Fisheries and Oceans Canada

Pêches et Océans Canada

Ecosystems and Oceans Science

Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat

Pacific Region

Science Response 2023/009

APPLICATION OF THE BRITISH COLUMBIA SABLEFISH (*ANOPLOPOMA FIMBRIA*) MANAGEMENT PROCEDURE FOR THE 2023-24 FISHING YEAR

Context

Fisheries and Oceans Canada (DFO) and the British Columbia (BC) Sablefish (*Anoplopoma fimbria*) fishing industry collaborate on a Management Strategy Evaluation (MSE) process intended to provide a transparent and repeatable harvest strategy. Total allowable catch (TAC) advice is provided annually to DFO Fisheries Management based on the application of a Management Procedure (MP) to updated stock index and landings data.

The Sablefish MP is a specific, repeatable algorithm for computing a recommended annual catch limit ('MP catch limit'). Criteria for selecting the MP for application to the fishery are based on performance statistics compiled during simulation testing of candidate MP options, where each statistic summarizes an outcome related to a specified management objective. Uncertainty and robustness are considered by testing each candidate MP against alternative scenarios for Sablefish stock and fishery dynamics defined by operating models (OMs). MPs that do not meet imperative objectives related to conservation are rejected from consideration. For MPs that do meet conservation objectives over a range of alternative scenarios, the final selection of an MP is based on examining trade-offs among management outcomes linked to socio-economic objectives.

Since 2011, annual total allowable catch levels (TACs) used to manage Sablefish fisheries have been informed by application of a simulation-tested MP as part of the MSE process, with the MP catch limit being adopted as the TAC in most years (Appendix, Table 1). Each year, under the terms of a Collaborative Agreement, DFO Science and the Canadian Sablefish industry work together to apply the selected MP to data in order to calculate the MP catch limit for the upcoming fishing year. Consistent application of the same MP to the fishery over multiple years is expected to lead to management outcomes that are similar to simulated performance. However, the MP may be revised when OM scenarios are updated based on new information, or changes are made to fishery management objectives. The MP is not used to evaluate stock status and serves only as a means of calculating a recommended catch limit based on the most recent monitoring data.

DFO Fisheries Management has requested that Science Branch evaluate the effect of updated data on annual MP application and resulting harvest advice for 2023-24. This Science Response applies the Sablefish MP to data updated to the end of 2022. The resulting MP catch limit informed the TAC for the 2023-24 fishing year. This is the first time that annual application of the Sablefish MP has been documented in this format. Accordingly, the document provides background on the MSE process, as well as stock summary information on sustainability elements required by DFO's *Fishery Decision-Making Framework Incorporating the Precautionary Approach* ('PA Policy'; DFO (2009)).

This Science Response results from the regional peer review on the Application of the Sablefish Management Procedure on January 31, 2023.

Canadä

Background

BC Sablefish Management Strategy Evaluation

Management strategy evaluation (MSE) is a process of designing and implementing a management-oriented paradigm in fisheries (de la Mare 1998). Rather than focusing solely on optimal yield, a management-oriented paradigm emphasizes making decisions that consider a broader range of strategic ecological, social, and economic objectives that define fisheries sustainability (Lane and Stephenson 1995; Cox and Kronlund 2008; Cox et al. 2011; Punt et al. 2016). Furthermore, emphasis is placed on making decisions that are robust to uncertainties in stock and fishery dynamics rather than focusing on a single 'base case' assessment model. A suitable means of setting fishing limits is identified by evaluating the performance of alternative management options, called management procedures (MPs), against operational fishery objectives. MPs are a specified set of data, stock assessment method, and harvest control rule that provides a means of calculating management actions on a repeatable basis. In the case of the Sablefish MP, the management action is a catch limit since the fishery is managed using an annual TAC.

The iterative Sablefish MSE process consists of (i) setting or modifying fishery objectives in response to policy requirements, desired stock conditions, and socio-economic goals, (ii) identifying candidate MPs that are feasible to implement, (iii) evaluating the performance of those MPs against uncertain stock and fishery dynamics, and (iv) selecting an MP for annual application to the fishery. The intention of the Sablefish MSE process is to select an MP that can be repeatedly applied to produce a catch limit each year using updated monitoring data, rather than directly choosing a catch each year or for a period of years (Figure 1).
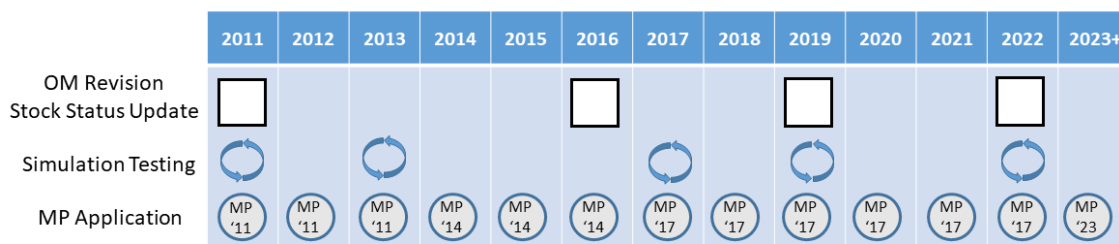

Figure 1. Timeline of operating model (OM) revisions (white squares), simulation testing of management procedures (blue arrows), and management procedure (MP) application (circles with year numbers '11-'23). Stock status is updated at each OM revision. The MP used from 2011 to 2013 (MP '11) used the maximum target harvest rate estimated by the MP's SSPM assessment model. A minimum catch floor was introduced to the MP from 2014-16, while the maximum harvest rate continued to be estimated by the SSPM (MP '14). The catch floor was removed in 2017 (MP '17) and a stepwise ramp down of the maximum target harvest rate occurred from 2017 (9.5%) to 2022 (5.5%) (MP '17). An MP with a maximum target harvest rate of 6.4% was applied beginning in 2023 (MP '23).

Sablefish Fishery Objectives

Five objectives for the BC Sablefish fishery have been iteratively developed via consultation with fishery managers, scientists, and Sablefish fishery stakeholders. These objectives are used to guide the choice of MP during the evaluation stage of the MSE. Once an MP is selected based on simulated performance relative to these objectives, it is applied annually until the next round of MP evaluation. Objectives 1-3 embed fishery reference points based on maximum sustainable yield (MSY), including a limit reference point (LRP), an upper stock reference (USR) and a target

reference point (TRP) consistent with the DFO PA Policy (DFO 2009). Objectives 4-5 are socio-economic objectives related to legal-sized Sablefish ($\geq$ 55 cm fork length) catch levels.

The five objectives used to evaluate MP performance are:

1. **Avoid LRP:** Maintain female spawning stock biomass above the limit reference point of LRP = $0.4B_{MSY}$ in 95% of years measured over two Sablefish generations (36 years), where B_{MSY} is the female spawning biomass at maximum sustainable yield (MSY) for each operating model;

2. **Avoid stock decline when below USR at the beginning of the projection period:** When female spawning stock biomass is between $0.4B_{MSY}$ and $0.8B_{MSY}$ at the start of projections, limit the probability of decline over the next 10 years from very low (5%) at $0.4B_{MSY}$ to moderate (50%) at $0.8B_{MSY}$. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between the extremes;

3. **Achieve target biomass:** Maintain the 2052 female spawning stock biomass above the target reference point with a 50% probability, where the target reference point is (a) $B_{TRP} = B_{MSY}$ when B $\geq 0.8B_{MSY}$, or (b) $B_{TRP} = 0.8B_{MSY}$ when B < $0.8B_{MSY}$ (see below description of how the year 2052 was selected);

4. **Avoid economically unviable catch:** Maximize the probability that annual legal-sized catch levels remain above 1,992 tonnes, measured over two Sablefish generations; and

5. **Maximize legal-size catch:** Maximize annual legal-sized catch over 10 years, subject to Objectives 1-4 being met.

The objectives are measurable; each objective has an associated performance statistic calculated during simulation testing that quantifies the degree to which an objective is satisfied (Cox et al. 2019a; DFO 2020). Spawning stock biomass for objectives 1-3 is quantified as female-only spawning stock biomass, as is a common practice in stock assessment.

Conservation objectives (i.e., Objectives 1 and 2) directly reflect the DFO PA Policy. Objective 1 ("Avoid LRP") aims to avoid undesirable biological outcomes by constraining the choice of an MP to those that avoid breaching the LRP with high probability. Objective 2 ("Avoid stock decline when below the USR") is a literal interpretation of the DFO PA Policy, specifying a linear reduction in tolerance for further stock decline from moderate (risk neutral) probability (50%) at $0.8B_{MSY}$ to very low probability (5%) at $0.4B_{MSY}$. Those MPs that do not show simulation performance consistent with the constraints imposed by Objectives 1-2 are rejected from consideration. Objective 2 also addresses the PA Policy intent to introduce corrective management action well in advance of reaching the LRP and provides a pre-specified foundation for a rebuilding plan should the stock decline to an undesirable level.

Objective 3 ("Achieve target biomass") serves to constrain MP choice to those that can achieve a target stock level in 2052 with at least a 50% probability. While the overall target stock level for BC Sablefish is B_{MSY}, Objective 3 allows a target of $0.8B_{MSY}$ to be used when stock status is lower than $0.8B_{MSY}$. The target applied during MP testing (B_{MSY} vs. $0.8B_{MSY}$) is dependent on stock status at the beginning of the projection period. The alternative target of $0.8B_{MSY}$ was introduced to objectives in 2017 based on recognition that it can take many years to reach B_{MSY} when stock status is low, depending on stock productivity. The year 2052 was also selected in 2017, at which time it was two generations into the future. This year has been held constant in

the last few rounds of MP evaluation to maintain a consistent target, but will be re-considered in the future as objectives are reviewed.

Sablefish MP

The Sablefish MSE attempts to capture the entire process that gives rise to a recommended catch limit; therefore, it is critical that candidate MPs be fully specified so that they can be consistently applied over time in simulation and in practice. For Sablefish, the MP includes:

1. Data - total landed catch and three abundance indices,

2. An assessment method – a tuned Schaefer state-space production model (SSPM) to extract a signal of stock trend,

3. A harvest control rule (HCR) – converts outputs from the assessment method in step 2 into a catch limit,

4. A post-HCR rule - catch limit increases are only recommended if they exceed the previous year's TAC by 200 t (there is no constraint on catch limit decreases).

Component (3) meets the PA Policy requirement for a HCR; however, the Sablefish MSE process simulation tests all four components together since MP performance is dependent on the interactions among the data, assessment method, HCR, and post-HCR rule. Critically, the MP establishes a feedback control link between current stock status and future stock response by adjusting catches downwards when the stock is perceived to decline and increasing catches as stock abundance increases.

Component (4) serves to eliminate minor increases in the MP catch limit that may generate disproportionate responses in Sablefish market economics.

Operating Models and Performance Evaluation

Operating Models

Mathematical models called operating models (OMs) are a key component of the MSE process with two key purposes. First, they represent alternative scientific hypotheses about uncertain stock and fishery dynamics that are used to generate simulated catch, survey and biological data that can be collected in practice. These simulated data are utilized during the evaluation of MP performance. Second, OMs are used to characterize stock status relative to fishery reference points.

The BC Sablefish MSE process involves updating the OM every 3-5 years to incorporate new data and hypotheses about Sablefish stock and fishery dynamics. The most recent update to the Sablefish OM was in 2022, which was subject to a CSAS regional peer review process (DFO 2023). The OM is a sex- and age-structured statistical catch-at-age model fit to fishery-specific landed catch from three gear types (trap, longline hook, and trawl; 1965 - 2021), as well at-sea releases from each gear type (2006 - 2021), three catch-per-unit effort (CPUE) indices of abundance, and age and length composition data. The three abundance indices used include trap fishery CPUE (1979 - 2009), a standardized survey (Std; 1990 - 2009), and a stratified random survey (StRS; 2003 - 2021).

The most recent estimates of BC Sablefish stock status relative to reference points are provided below.

Evaluation

Prior to application to the actual fishery, the expected performance of candidate Sablefish MPs is evaluated via closed-loop simulation. This evaluation step provides the opportunity to expose the range of catch/conservation performance trade-offs among candidate MPs. Moreover, by testing MPs against a range of OMs representing key uncertainties, MP evaluation checks that applying a specific MP will not produce undesirable outcomes, even if key assumptions about the stock (e.g., biomass, productivity) and fishery (e.g., selectivity, precision parameters used to fit at-sea releases) are incorrect.

During the evaluation component of the MSE, stock dynamics are projected into the future by the OM, and at each time step the MP is applied to simulated data in a closed-loop that represents the annual application of the MP in practice, including collecting data, applying an assessment method, and translating assessment outputs into a catch limit via the HCR. Performance statistics related to operational objectives (1-5) are derived from simulated stock projections and used to rank the relative performance of candidate MPs.

Simulation testing of MP options is typically done at the same time as OM updates, or soon after, to confirm acceptable performance of the existing MP or to identify an alternative MP with superior performance. MPs that fail to provide acceptable performance outcomes in simulation are unlikely to work well in practice and are rejected from consideration. The fishery management decision is to select an MP that provides acceptable performance trade-offs until the OM is again revised and MPs re-evaluated. The OM revised in 2022 was used to simulation test the performance of a suite of alternative MPs that varied the maximum target harvest rate applied within the HCR from 5.5% to 7.5% (DFO 2023).

Current Status of BC Sablefish Relative to Reference Points

Under the Fish Stocks provisions of the revised Canadian *Fisheries Act* (*Fisheries Act* R.S.C., 1985, c. F-14, as amended by Bill C-68, June 21 2019), there is a legal requirement to maintain major fish stocks at levels necessary to promote sustainability, and to develop and implement rebuilding plans for stocks that have declined below their LRPs. Estimates of stock status relative to reference points are expected to be one type of information used by DFO to evaluate fisheries sustainability under the *Fisheries Act* (Marentette et al. 2021). In the Sablefish management system, OMs are used to characterize status. The most recent OM update took place in fall of 2022 using data to the end of 2021 (DFO 2023; Johnson et al., In prep.[1]). Stock status in 2022 was assessed via a weighted-average of five operating model scenarios representing uncertainty about productivity and recent (2021) female spawning stock biomass (hereafter denoted as B). OM scenario weights were based on plausibility values assigned by analysts. A weight of 50% was assigned to the base operating model that was believed to provide a balanced fit to release data, age composition data, and length composition data. Values of 12.5% were assigned to each of the other four OMs that varied productivity and recent female spawning biomass relative to the base model.

Reconstructed historic time series from the operating model (1965–2021) characterize a consistent decline in spawning stock biomass between 1965 and 2008 (Figure 2). During this period, occasional years of relatively strong recruitment led to brief periods of increasing or stabilized biomass. However, high catch levels and harvest rates that were frequently above the harvest rate at

---

[1]Johnson, S.D.N., Cox, S.P., Holt, K.R., Lacko, L.C., and Rooper, C.N. In prep. Stock status and management procedure performance for the BC Sablefish (*Anoplopoma fimbria*) fishery for 2022/23. Can. Sci. Advis. Sec. Res. Doc.

maximum sustainable yield, U_{MSY}, contributed to reductions in biomass as these waves of recruitment were fished. Biomass levels stabilized around 2008-2011 when estimated harvest rates were reduced to levels below current estimates of U_{MSY} obtained in 2022. Recent above-average recruitment events in 2015-2017, with 2016 and 2017 in particular being by far the largest in the reconstructed time series, have resulted in a substantial increase in biomass through to 2022 (Figure 2), as well as an increase in estimated stock recruitment productivity. For Sablefish, stock status is estimated using the ratio of female spawning biomass, B, to each
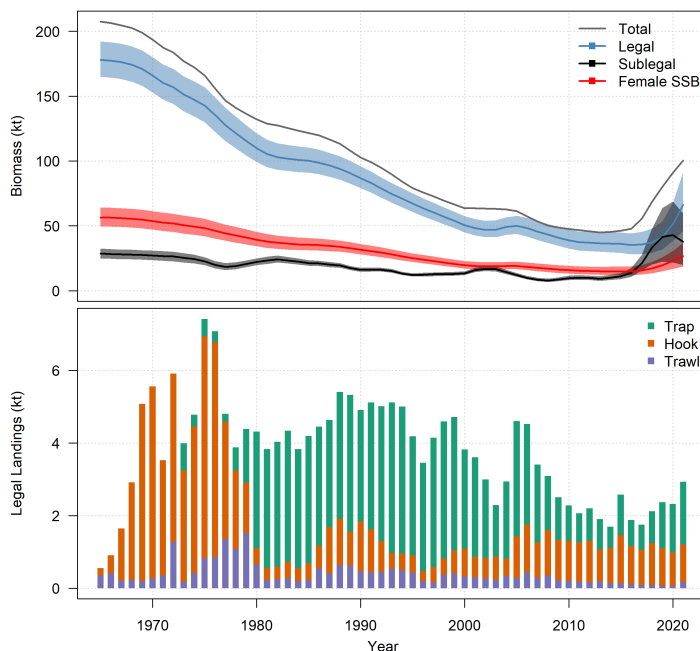

Figure 2. Top row: Time series of total biomass, legal-sized biomass, sub-legal-sized biomass, and female spawning biomass (SSB) estimates based on weighted averages over the five OM scenarios used in 2022. Note that total, legal, and sub-legal biomass estimates include both female and male fish, while SSB is shown for only female Sablefish. Bottom row: total legal-sized Sablefish landings from each gear type. Figures reproduced from DFO (2023).

fishery reference point. For example, status in year t relative to the LRP is defined as $B_t/0.4_{BMSY}$. A value greater than 1 indicates that B exceeds the LRP. Uncertainty in the estimate is communicated by stating the probability that B exceeds $0.4B_{MSY}$, i.e., $P(B > 0.4B_{MSY}) = 0.95$ indicates a very high probability that female spawning biomass exceeds the LRP.

Results of the most recent revision to the OM suggest there is a high probability that BC Sablefish was above the target biomass of B_{MSY} in 2022, and that the harvest rate in 2021 was below U_{MSY} (Appendix Table 2, DFO 2023). The weighted average female spawning biomass across the five OM scenarios was estimated at 30 kt, or around 1.32 times B_{MSY} ($P(B_{2022} > B_{MSY})$ = 92%), while the 2021 harvest rate of legal Sablefish was estimated to be 71% of U_{MSY} ($P(U_{2021} < U_{MSY})$ = 95%). When viewed individually, each of the five OM scenarios indicated a 100% probability of B_{2022} being above the LRP, and four of the five OMs estimated a 100% probability of B_{2022} being above the USR of $0.8B_{MSY}$. The OM scenario representing the lowest recent female spawning stock biomass indicated a 92% probability of B_{2022} being above the USR.

Analysis and Response

The steps required to apply the Sablefish MP include (i) updating input data to include 2022 catch landings and the 2022 catch per unit effort (CPUE) index from the annual Sablefish stratified random trap survey; (ii) fitting a state-space surplus production model (SSPM) to the updated dataset to generate an SSPM estimate of biomass; (iii) applying a HCR using SSPM estimates of operational control points and biomass to output a catch limit; and (iv) applying a post-HCR rule that allows a catch limit increase only if the updated value exceeds the previous year's TAC by 200 t. The result is called the MP catch limit. This section describes the steps required to apply the MP selected for application in 2023-24, which includes a maximum target harvest rate of 6.4%. MP selection was based on simulated performance relative to the Sablefish fishery objectives listed above.

Data

Data requirements for the current MP include total Sablefish landings from all BC fisheries and three CPUE indices of abundance: (i) commercial trap fishery CPUE (1979-2009), (ii) survey CPUE from the standardized trap survey (1991-2009), and (iii) survey CPUE from the stratified random trap survey (StRS; 2003-present). Each of these time series is provided in Table 3 of the Appendix.

The first two abundance indices are historical time series that are no longer updated. The methods used to develop these indices are documented in Cox et al. (2023).

The third abundance index is derived from the ongoing StRS survey; index values are updated annually as part of the MP application. The StRS survey was initiated in 2003 and follows a depth and area stratified random sampling design. The offshore survey area is partitioned into five spatial strata, each with three depth strata, for a total of 15 strata. The stratified random sampling mean index value and 95% confidence intervals are calculated using the classical survey stratified random sampling estimator (e.g., Cochran 1977). Detailed descriptions of coastwide stratified random survey results are summarized in annual survey reports (e.g., Lacko 2021). The StRS survey has relatively tight confidence intervals (Figure 3; coefficient of variation = 5.5 - 10%). While the low CVs may be partly due to the survey being designed specifically for Sablefish (as opposed to a multi-species survey), they are assumed to be underestimates of true variability. Higher CVs are used when simulating data from OMs during MP evaluation (Johnson et al., in revision).

In 2022, the StRS mean survey index was 40 kg/trap, which is 10% greater than the 2021 value and the second highest in the time series since it started in 2003 (Figure 3). Survey CPUE has often been highest in mid-depth strata, although, recent years have seen some of the largest CPUE values recorded in the shallow depth strata, in addition to the mid-depth strata (Appendix Figure 6). This trend continued in 2022 as the younger 2016-2017 year classes occupy that habitat, contributing to the increase in the annual abundance index.

The 2022 survey data were explored for unexpected or concerning signals that might suggest the OM or MP should be re-visited, but none were found. The stratified mean survey index of 40 kg/trap for 2022 was almost as large as the series maximum of 42 kg/trap in 2019. However, the number of fish and size of fish contributing to the CPUE differed somewhat between the two years. Survey catches in 2019 were dominated by relatively high numbers of small fish, while 2022 survey catches tended to contain fewer fish relative to 2019 and fish were larger in size (Appendix Figure 7). This pattern is to be expected as the large 2016-2017 cohorts move through the fishery and grow in body size. The distribution of set-specific survey CPUE values (in

units of kg/trap) in 2022 was similar to values observed over the previous two years, although the 2022 distribution had a larger positive skew indicating a few sets with very large CPUE values (Appendix Figure 7).
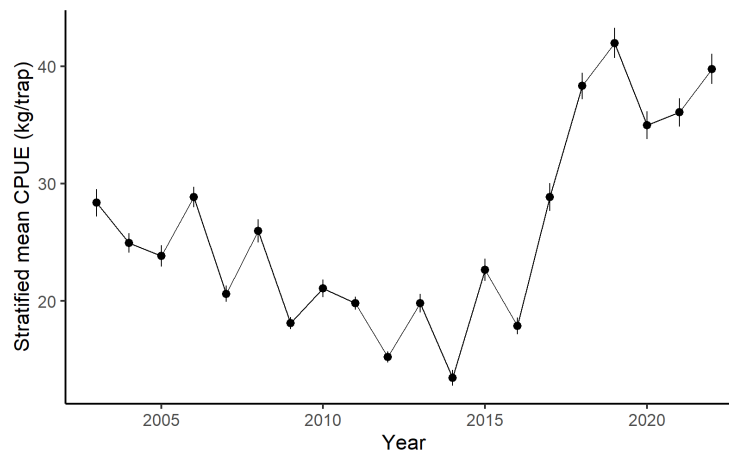

Figure 3. Estimated coastwide Sablefish biomass index from the stratified randomized survey (StRS) over time, shown as the stratified mean CPUE (points) and 95 confidence interval (error bars).

Landings of legal-size Sablefish were also updated as part of the MP application. A total legal-sized landed catch of 2,952 tonnes was used for 2022. While this value was not finalized as of 09-January-2023, it is expected to be very close to the finalized catch for 2022. It includes all reported landed catch from the 2022 calendar year that was available as of 09-January-2023, plus an estimate of catch still to be landed from late-December 2022 that was obtained from skippers that were still fishing in early January. Reported landings are considered to be known without error due to 100% at-sea and dockside monitoring.

Retention of sub-legal sized Sablefish is known to occur in the trawl fishery, especially mid-water trawl Pacific Hake (*Merluccius productus*) fishery, for which sorting at sea is challenging due to small Sablefish being hard to detect in large tows of Pacific Hake. Since 2017, estimates of sub-legal retained catch from the trawl fishery have been explicitly removed from landed catch estimates used in the SSPM model. Further work is needed prior to next year's MP application to better understand how sub-legal fish were recorded prior to 2017.

Assessment: Surplus Production Model

The stock assessment component of the Sablefish MP consists of fitting a state-space surplus production model (SSPM) to the data series describe above and shown in Appendix Table 3. The SSPM model is now implemented using Template Model Builder (TMB) (Kristensen et al. 2015). The transition to TMB for both the OM and SSPM in the MP was documented by Johnson et al. (in revision). Prior to 2022, both models were implemented using the now unsupported AD Model Builder software (Fournier et al. 2012).

The biomass trajectory estimated by the SSPM (B'_t) is shown in Figure 4, where the notation B'_t is used to denote biomass estimated from the SSPM model. This biomass differs from the female spawning biomass B_t estimated by the OM and used for status determination. The SSPM estimate of biomass for 2023, B'_{2023} is 47,325 tonnes.
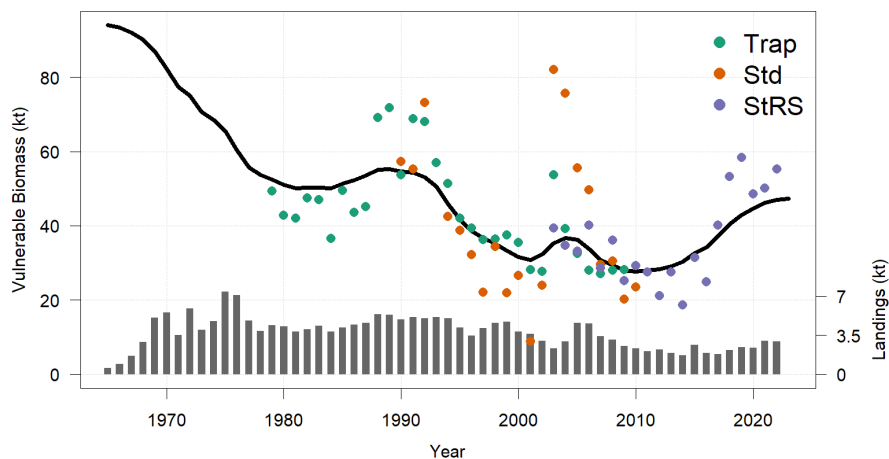
Figure 4. Total BC Sablefish landings (bars), scaled abundance indices (points), and MP-estimated Sablefish biomass from the SSPM model (black line). Abundance indices have been scaled by estimated catchability for the three different abundance indices used to fit the SSPM model: trap fishery CPUE (Trap), the standardized survey series (Std), and the stratified random survey series (StRS).

The increasing SSPM biomass trajectory beginning in the late-2010s is a result of substantial increases in the StRS survey index since 2017. The SSPM model under-fits StRS indexing points over the last five years, a behaviour expected from surplus production models and accounted for when simulation-testing candidate MPs (Cox et al. 2019a). The fit of the SSPM to the indexing points is less important than the performance of the overall MP (data, assessment, and HCR) against the Sablefish fishery objectives. Within the MP, the SSPM simply serves as an indicator of stock trend for input to the HCR so that fishing pressure is reduced when abundance is perceived to decrease, and increased when stock abundance grows.

Despite the increasing trend in SSPM estimated biomass, the 2023 estimate used to provide catch advice for the 2023-24 fishing year is lower than the 2022 estimate. This difference is due to a decrease in the overall estimated scale of the population obtained from the TMB implementation of the SSPM when compared to the ADMB implementation. The difference in scale is evident when comparing $\hat{B'_{MSY}}$ estimates between the two years. The SSPM model estimate of $\hat{B'_{MSY}}$ for 2023 is 46,997 tonnes, while that from last year's ADMB fit of the SSPM was 48,793 tonnes. This outcome reflects the change in software platform and one additional year of data.

Harvest Control Rule

The BC Sablefish Harvest Control Rule (HCR) calculates a target harvest rate based on a maximum target harvest rate and the SSPM estimate of biomass relative to two operational control points (OCPs); a lower control point (LCP) set at the SSPM estimate of $0.4\hat{B'_{MSY}}$ and an upper control point (UCP) set at $0.6\hat{B'_{MSY}}$ (Figure 5). Once again, B' is used to denote the SSPM estimates of biomass, and $\hat{B'_{MSY}}$ is used to denote the SSPM estimate of biomass at MSY. The HCR is

defined by the recti-linear function:

$$
U_t = \begin{cases} 0 & \hat{B}'_t \le 0.4B'_{MSY} \\ U_{max} \cdot \frac{\hat{B}'_t - 0.4\hat{B}'_{MSY}}{0.6\hat{B}'_{MSY} - 0.4\hat{B}'_{MSY}} & 0.4\hat{B}'_{MSY} < \hat{B}'_t \le 0.6\hat{B}'_{MSY} \\ U_{max} & 0.6\hat{B}'_{MSY} < \hat{B}'_t \end{cases} \quad , \tag{1}
$$

where U_{max} is the maximum target harvest of rate. Again note that $\hat{B'}_{MSY}$ is not the operating model estimate of B_{MSY} used to define fishery reference points that was described above. Depending on the value of $\hat{B}'_t$, the target harvest rate U_t may be adjusted downwards from U_{max} to reduce fishing pressure and promote stock growth when required.

The 2023-24 Sablefish MP applies a U_{max} of 6.4%. The SSPM estimated biomass for 2023 is well above the estimated upper OCP of $0.6\hat{B}'_{MSY}$, which means that the target harvest rate U_t prescribed by the HCR (i.e., using equation 1) is U_{max} = 6.4% (Figure 5).

The target harvest rate is then multiplied by the SSPM-estimated biomass to produce an unadjusted catch limit for year t, i.e., $Q'_t = U_t \hat{B}'_t$. The unadjusted catch limit Q'_{2023}, based on U_{2023} = 6.4% and $\hat{B}'_{2023}$ = 47,325 tonnes is 3,029 tonnes.
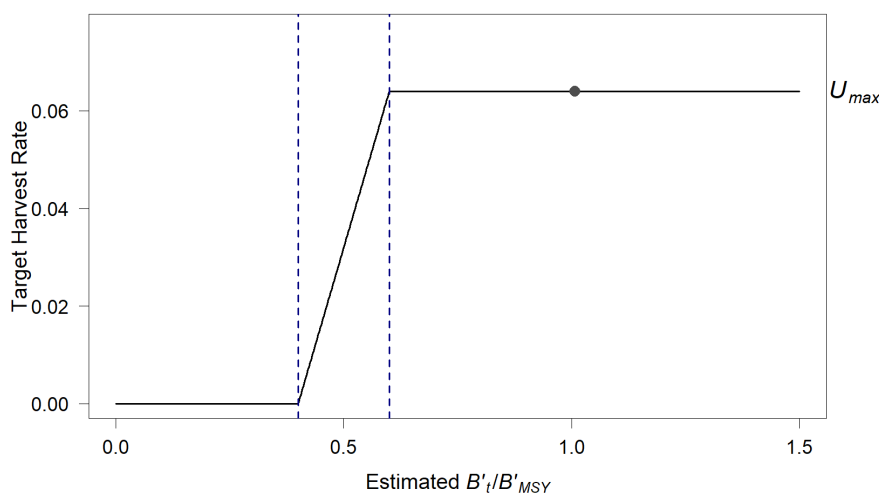

Figure 5. Sablefish harvest control rule (HCR; solid line) showing the target harvest rate as a function of maximum harvest rate U_{max} and the estimated biomass from the SSPM model component of the MP relative to the SSPM estimate of $\hat{B'}_{MSY}$. Operational control points occur at the SSPM estimates of $0.4\hat{B'}_{MSY}$ and $0.6\hat{B'}_{MSY}$ (vertical dashed lines). Forecasted 2023 biomass from the SSPM model (black point) is shown on the HCR.

Post-HCR Adjustment

In the final step of the MP, a minimum catch limit increase criterion of 200 tonnes is applied post-HCR to determine the MP catch limit:

$$
Q_t = \begin{cases} Q'_t & Q'_t - Q_{t-1} \ge 200 \\ Q_{t-1} & 0 < Q'_t - Q_{t-1} < 200 \\ Q'_t & Q'_t - Q_{t-1} \le 0 \end{cases} \tag{2}
$$

where Q'_t is the catch limit output by the HCR, Q_{t-1} is last year's TAC, and Q_t is the MP catch limit in year t (all units are in tonnes). The criterion accepts a catch limit increase if it exceeds

last year's TAC by 200 tonnes, otherwise last year's TAC is taken as the MP catch limit. There is no constraint on catch limit decreases.

Because the catch limit Q'_t for 2023-24 is over 200 tonnes greater than last year's TAC of 2,623 tonnes, the post-HCR adjustment from equation 2 does not affect the 2023-24 catch limit. The catch limit for 2023-24 is the 3,029 tonne value calculated from the HCR above, which is a 15 % increase from last year's TAC.

Conclusions

Precaution in Sablefish MP Selection and Application

Precautionary fisheries management involves systems that measure catches and abundance, rules that determine how catches should be adjusted in relation to stock and fishery monitoring data, and enforcement of management actions (Hilborn 2002). In particular, Sablefish management includes the core requirements for fisheries sustainability identified by Hilborn et al. (2015):

1. Specific objectives for abundance and fishing pressure,

2. Monitoring of fishing pressure for Sablefish via 100% at-sea electronic monitoring of retained and released catch coupled with dockside validation of landings, and monitoring of abundance via an annual fishery-independent Sablefish abundance survey and tag release-recovery program,

3. Assessments to determine if targets are being met according to pre-determined performance metrics via regular revisions to the Sablefish operating model that reflect new knowledge and data,

4. Feedback control via application of a simulation-tested MP that adjusts fishing pressure in response to the assessments of stock trajectory, and

5. Enforcement systems to assure compliance with regulations via catch monitoring in (1) and the activities of DFO's Conservation and Protection Branch.

Specific objectives used to inform the selection of the Sablefish MP (requirement 1) meet legislative requirements under the Fish Stocks provisions of the *Fisheries Act* by defining both conservation and use of the stock over time periods commensurate with definitions of sustainability (Marentette et al. 2021). For example, Sablefish conservation objectives described in the 'Background' section reflect the policy goal to avoid undesirable biological outcomes. Sablefish objectives are hierarchically structured in such a way that the management choice is constrained to an MP that has a high probability of stock status remaining above the LRP over a time period of 36 years, which corresponds to two Sablefish generations.

Consistent application of an MP that outputs an annual catch limit (Requirement 4, above) has several advantages. First, a strong feedback link is created between current management action and future stock response such that catches are reduced when stock abundance declines and can be increased as stock abundances grows. Second, how a catch limit is calculated is fully specified by the MP and reproducible. Finally, an MP catch limit can be provided every year, without having to do a "full stock assessment", provided the inputs to the MP are available (e.g., landings and the trap survey index for the BC Sablefish MP).

Another key component of precautionary fisheries management systems is the explicit consideration of uncertainty when developing management measures (FAO 1996). Prospective evaluation of proposed management actions via simulation, such as that undertaken as part of the Sablefish

MSE process, reinforces precaution by testing the performance of candidate MPs over a range of uncertain scenarios about stock and fishery dynamics (FAO 1996). This simulation step allows MPs that perform poorly in simulation to be rejected, which acts as a risk mitigation step. Although the simulation testing does not guarantee the realized performance of an MP will match simulation performance, exposing candidate MPs to data simulated under a range of uncertain stock and fishery dynamics using operating models closes the gap between precaution in theory and practice (FAO 1996; Cox et al. 2019b). The selection of the current Sablefish MP used to inform catch limits for the 2023-24 fishing year was based on evaluation over five operating model scenarios to ensure that the MP would meet established fishery objectives for each of the five scenarios (DFO 2023). These five scenarios covered two key axes of uncertainty: stock-recruitment steepness (productivity) and terminal biomass in the last year of the assessment.

Additional elements of the management system also reinforce precaution. For example, Sablefish stock management in BC receives annual attention. The coastwide stock is indexed each year by the dedicated area- and depth-stratified random trap gear survey which is very selective for Sablefish and achieves relatively high sampling precision. Application of the Sablefish MP means that the survey data are analyzed each year and can be compared to the range of plausible outcomes projected by the simulation testing. Large departures of realized performance from that projected in simulation are likely to be noticed, allowing for corrective intervention when required. In addition, annual calculation of operational control points and stock trajectory by the SSPM component of the MP means that the harvest rate applied by the fishery is adjusted, if necessary, from the maximum target harvest rate if the stock declines towards the LRP. Finally, periodic (3-5 year) revision of the Sablefish operating model allows for (i) updating of stock status, (ii) consideration of new data and hypotheses or elimination of those hypotheses for which there is low support, and (iii) re-evaluation of MP performance against management objectives. Appendix Table 2 provides a summary of attributes of the Sablefish management system that describe compliance with regulations supporting the Fish Stocks provisions as well as Canada's domestic harvest policy (DFO 2009).

MP Catch Limit for the 2023/24 Fishing Year

The Sablefish MP was applied to stock and fishery monitoring data updated to 2022. The StRS abundance index for 2022 was 40 kg/trap, which is an increase of 10% from 2021 and the second highest on record since the time series started in 2003. Similarly, the SSPM estimate of biomass continued to show the increasing trend seen in recent years. Estimated SSPM biomass for 2023 was the highest since 1993 and is well above the upper OCP of $0.6\hat{B}'_{MSY}$. As a result, the target harvest output from the HCR is the maximum target harvest rate of 6.4%, i.e., no precautionary reduction from U_{max} is required for the coming fishing year.

The MP selected for application beginning with the 2023/24 fishing year resulted in an MP catch limit of 3,029 tonnes. Barring unexpected signals in the survey data, the intent of the MSE process is to consistently apply this MP until the next operating model revision, which is expected to occur between 2025 and 2028. Stock status will be updated at that time and the performance of the existing MP and alternatives re-evaluated via simulation testing.

Contributors

Name	Affiliation
Kendra Holt	DFO Science, Pacific Region
A.R. Kronlund	Interface Fisheries Consulting Ltd.
Sam Johnson	Landmark Fisheries Research
Sean Cox	Landmark Fisheries Research
Darah Gibson	DFO Fisheries Management, Pacific Region
Deirdre Finn	DFO Fisheries Management, Pacific Region (reviewer)
Robyn Forrest	DFO Science, Pacific Region (reviewer)
Brian Mose	Canadian Groundfish Research & Conservation Society (reviewer)
Bruce Turris	Canadian Groundfish Research & Conservation Society (reviewer)

Approved by

Andrew Thomson
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada

May 4, 2023

Sources of Information

Cochran, W.G. 1977. Sampling Techniques. *In* 3rd edition. Wiley and Sons, New York.

Cox, S., Holt, K., and Johnson, S. 2019a. Evaluation the Robustness of Management Procedures for the Sablefish (*Anoplopoma Fimbria*) Fishery in British Columbia, Canada for 2017-18. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/032. vi + 79 p.

Cox, S., Kronlund, A., and Lacko, L. 2011. Management procedures for the multi-gear Sablefish (*Anoplopoma Fimbria*) fishery in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/063. viii + 45 p.

Cox, S.P., Benson, A.J., Cleary, J.S., and Taylor, N.G. 2019b. Candidate Limit Reference Points as a Basis for Choosing Among Alternative Harvest Control Rules for Pacific Herring (*Clupea pallasii*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/050. viii + 47 p.

Cox, S.P., and Kronlund, A.R. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada. Fisheries Research 94(3): 224–237.

Cox, S.P., Kronlund, A.R., Lacko, L., and Jones, M. 2023. A revised operating model for Sablefish in British Columbia, Canada in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/023. vii+127 p.

de la Mare, W.K. 1998. Tidier Fisheries management requires a new MOP (management-oriented paradigm). Rev. Fish Biol. Fish. 8: 349–356.

DFO. 2009. A fishery decision-making framework incorporating the precautionary approach.

DFO. 2020. Evaluating the robustness of candidate management procedures in the BC Sablefsh (*Anoplopoma Fimbria*) Fshery for 2019-2020. DFO Can. Sci. Advis Sec. Sci. Resp. 2020/025.

DFO. 2023. A revised operating model for Sablefish in British Columbia in 2022. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/010.

FAO. 1996. Precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries. Lysekil, Sweden, 6-13 June 1995. FAO Technical Guidelines for Responsible Fisheries No. 2: 54 p.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: Using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27(2): 233–249.

Hilborn, R. 2002. The Dark Side of Reference Points. Bull. Mar. Sci. 70(2).

Hilborn, R., Fulton, E.A., Green, B.S., Hartmann, K., Tracey, S.R., and Watson, R.A. 2015. When is a fishery sustainable? Can. J. Fish. Aquat. Sci. 72(9): 1433–1441.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B. 2015. TMB: Automatic Differentiation and Laplace Approximation. arXiv preprint arXiv:1509.00660.

Lacko, L.C. 2021. Summary of the annual 2020 sablefish (*Anoplopoma Fimbria*) trap survey, October 7 - November 21, 2020. DFO Can. Tech. Rep. Fish. Aquat. Sci. 3431: vi + 50 p.

Lane, D.E., and Stephenson, R.L. 1995. Fisheries management science: The framework to link biological, economic, and social objectives in fisheries management. Aquat. Living Resour. 8(3): 215–221.

Marentette, J.R., Kronlund, A.R., Healey, B., Forrest, R.E., and Holt, C.A. 2021. Promoting sustainability in the context of the fish stocks provisions and the fisheries decision-making framework incorporating the precautionary approach. DFO Can. Sci. Advis. Res. Doc. 2021/062. viii + 51 p.

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., and Haddon, M. 2016. Management strategy evaluation: Best practices. Fish Fish 17(2): 303–334.

Appendix

Table 1. Summary of Sablefish management targets and resulting TACs from application of Sablefish Management Procedures (MPs) since 2011. Quantities shown include the maximum harvest rate permitted by that year's MP (Umax), the calculated target harvest rate for a year based on the 'MP estimate' of stock status (Target U), the catch limit prescribed the the MP (MP Catch Limit; units = tonnes), and the final adopted TAC used for management. Note that harvest rate is a function of biomass estimated by the surplus production model in the MP, not the OM estimated biomass. The Sablefish Advisory Committee (SAC) is an advisory body to DFO.

Year	Umax	Target U	MP Catch Limit	TAC	Notes
2011-12	10.5	10.5	2254	2300	OM and MP revised (Cox et al. 2011). Maximum target harvest rate, Umax, estimated by SSMP until 2017-18.
2012-13	10.3	10.3	2293	2293	
2013-14	9.5	9.1	1992	1992	MP revised (DFO 2014)
2014-15	9.5	9.5	2192	2192	
2015-16	8.2	6.1	1992	1992	
2016-17	8.6	7.5	1992	1992	OM revised (DFO 2016, Cox et al. 2023)
2017-18	9.5	8.6	2276	2276	MP revised (DFO 2017, Cox et al. 2019). Maximum target harvest rate based on tuning in simulation beginning in 2017-18.
2018-19	8.7	8.7	2720	2526	SAC recommended a TAC set below the MP catch limit to enhance rebuilding efforts and allow time for recent recruitment to grow biomass.
2019-20	7.9	7.9	2955	2526	SAC recommended a target harvest rate of 7.1% instead of 7.9% to reduce fishing pressure on juvenile Sablefish and promote continued biomass growth. Operating model underwent minor updates (DFO 2020).
2020-21	7.1	7.1	3057	3057	
2021-22	6.3	6.3	2887	2887	
2022-23	5.5	5.5	2623	2623	

Table 2. Policy compliance of the Sablefish Management System with the Fish Stocks provisions and PA Policy (DFO 2009). Stock status estimates are taken from DFO 2023.

Component	Description
Stock	Sablefish (Pacific, Coastwide)
Management Paradigm	Management Strategy Evaluation (MSE)
	Simulation-tested Management Procedure (MP, defined below) for annual TACs consistent with objectives (defined below)
	Operating models (OMs) updated on a 3-5 year cycle for stock assessment and MP simulation testing
Reference Points	MSY-based reference points estimated by OMs on a 3-5 year MSE / stock assessment cycle
	* Limit Reference Point: LRP = $0.4B_{MSY}$
	* Upper Stock Reference: USR = $0.8B_{MSY}$
	* Target Reference Point: TRP = B_{MSY}
Assessment / Operating Model	Weighted ensemble of 5 age-/sex-structured operating models with uncertainty characterized via Bayes posteriors. Assessment/operating models fitted to biomass indices (fishery and 2 survey), age composition (fishery and 2 surveys) and at-sea releases of sub-legal Sablefish, along with auxiliary data from > 30 years of tag release/recovery programs.
Management Procedure:	
a. Data	Trap fishery CPUE (1979-2009)
	Standardized trap survey (1990-2009)
	Stratified random trawl survey (2003-2021)
	Landings (1965 - 2021)
b. Assessment method	Schaefer state-space production model (SSPM) fitted to data described in (a) above
c. HCR	Hockey stick shape with two SSPM-estimated control points:
	* Lower control point: LCP = $0.4B_{MSY}$
	* Upper control point: UCP = $0.6B_{MSY}$
	Removal reference:
	* Maximum target harvest rate in 2023 = 6.4%. Control points estimated annually by the SSPM. Maximum target harvest rate selected via tuning simulated MP performance against objectives (defined below)

Component	Description
Stock Status (2022):	
a. Female spawning biomass	Stock is above B_{MSY}
	B_{2022} = 29.9 kt (95% CI: 19.6 kt - 42.9 kt)
	B_{2022}/B_{MSY} = 1.32
	Stock is above LRP with high probability:
	$P(B_{2022} > LRP)$ = 100%
	Stock is above USR with high probability:
	$P(B_{2022} > USR)$ = 99%
	Stock is above TRP with moderate probability:
	$P(B_{2022} > TRP)$ = 92%
b. Harvest rate	Harvest rate is less than U_{MSY} with high probability:
	$P(U_{2021} < U_{MSY})$ = 94%
Rebuilding Plan	Not required
Rebuilding Criteria	Entry:
	Terminal year stock status estimated at or below LRP with greater than 50% probability
	Exit (Rebuilt state):
	Not required at present
Environmental Considerations	Mechanisms by which environmental conditions affect BC Sablefish are not understood at this time.
	An initial investigation of seven environmental variables (EVs) showed that none were strongly correlated to recruitment.
	While the impact of climate change on BC Sablefish is also unknown recent research indicates that increasing temperature may increase habitat suitability for BC Sablefish.
Objectives:	1) $P(B > B_{LRP}) \geq 0.95$: Maintain female spawning biomass above the limit reference point of $LRP = 0.4 B_{MSY}$ in 95% of years measured over 2 Sablefish generations

Component	Description
	2) $P(decline)$: When female spawning stock biomass is between 0.4B_{MSY} and 0.8B_{MSY}, limit the probability of decline over the next 10 years from very low at 0.4B_{MSY} to moderate (50%) at 0.8B_{MSY}. At intermediate stock status levels, define tolerance for decline by linearly interpolating between the extremes.
	3) $P(B_{2052} > B_{Targ})$ = 0.50: Maintain a 50% probability of female spawning biomass above the target reference point in 2052, where the target reference point is (a) B_{MSY} when $B \geq 0.8B_{MSY}$ and (b) $0.8B_{MSY}$ when $B < 0.8B_{MSY}$.
	4) max(P(C_t > 1,992 tonnes)): Maximize the probability that annual catch levels remain above 1,992 tonnes, measured over two Sablefish generations
	5) MaxCatch: Maximize the annual catch over 10 years

Table 3. Data used in the assessment model component of the Sablefish MP application for 2023/23, including catch landings (1000's of tonnes) and three CPUE abundance indices (kg / trap) from the Sablefish trap fishery (Trap), the standadized Sablefish survey (Std), and the Stratified Random Sablefish Survey (StRS).

Year	Landings	Trap	Std	StRS
1965	0.54	-	-	-
1966	0.90	-	-	-
1967	1.64	-	-	-
1968	2.91	-	-	-
1969	5.07	-	-	-
1970	5.55	-	-	-
1971	3.52	-	-	-
1972	5.90	-	-	-
1973	3.98	-	-	-
1974	4.78	-	-	-
1975	7.41	-	-	-
1976	7.07	-	-	-
1977	4.79	-	-	-
1978	3.87	-	-	-
1979	4.38	17.661	-	-
1980	4.31	15.312	-	-
1981	3.83	15.056	-	-
1982	4.03	16.973	-	-
1983	4.33	16.819	-	-
1984	3.83	13.059	-	-
1985	4.19	17.687	-	-
1986	4.45	15.602	-	-
1987	4.63	16.16	-	-
1988	5.40	24.736	-	-
1989	5.32	25.695	-	-
1990	4.91	19.222	20.018	-
1991	5.12	24.6	19.336	-
1992	5.02	24.363	25.57	-
1993	5.12	20.38	36.511	-
1994	5.01	18.397	14.834	-
1995	4.19	15.02	13.562	-

| Year	Landings	Trap	Std	StRS
1996	3.46	14.087	11.258	-
1997	4.14	12.956	7.722	-
1998	4.60	13.02	12.039	-
1999	4.71	13.426	7.651	-
2000	3.83	12.667	9.296	-
2001	3.61	10.082	3.08	-
2002	3.01	9.899	8.397	-
2003	2.33	19.222	28.656	28.371
2004	2.97	14.009	26.447	24.94
2005	4.62	11.615	19.432	23.831
2006	4.55	10.034	17.382	28.857
2007	3.42	9.705	10.348	20.61
2008	3.11	10.042	10.681	25.961
2009	2.52	10.09	7.084	18.121
2010	2.30	-	8.194	21.072
2011	2.07	-	-	19.807
2012	2.21	-	-	15.239
2013	1.93	-	-	19.796
2014	1.71	-	-	13.445
2015	2.61	-	-	22.642
2016	1.90	-	-	17.881
2017	1.80	-	-	28.866
2018	2.17	-	-	38.314
2019	2.41	-	-	41.964
2020	2.35	-	-	34.974
2021	3.01	-	-	36.059
2022	2.95	-	-	39.756
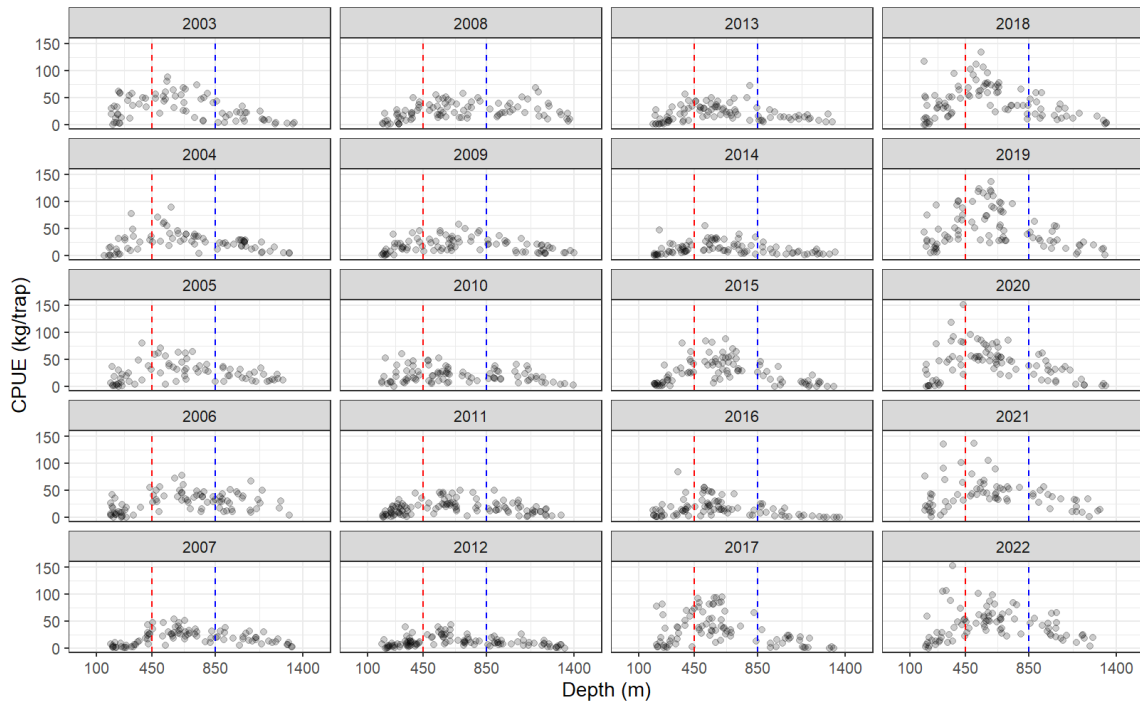
Figure 6. Sablefish catch per unit effort (CPUE) by depth and year. Dashed lines delineate depth strata (shallow = 100-450m, mid = 450-850m, deep = 850-1400m).
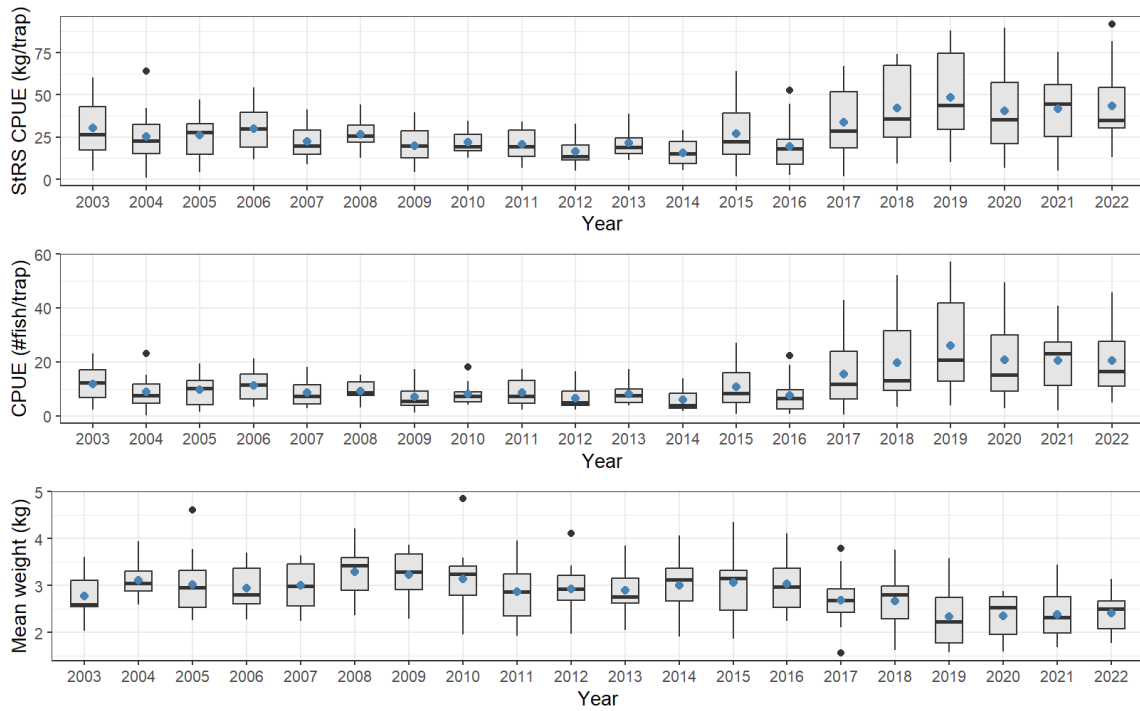
Figure 7. Top: Annual mean weight of sablefish per trap (kg/trap), Middle: annual mean number of sablefish per trap (fish/trap); Bottom: annual mean weight of sablefish (kg) by StRS survey strata over time. Horizontal line is median and blue dots are arithmetic mean.

This Report is Available from the:

Correct Citation for this Publication:

DFO. 2023. Application of the British Columbia Sablefish (*Anoplopoma fimbria*) Management
   Procedure for the 2023-24 Fishing Year. DFO Can. Sci. Advis. Sec. Sci. Resp. 2023/009.

Aussi disponible en français :

*MPO. 2023. Application de la procédure de gestion de la morue charbonnière
   (*Anoplopoma fimbria*) de la Colombie-Britannique pour l'année de pêche 2023-2024.
   Secr. can. des avis sci. du MPO. Secr. can. des avis sci. du MPO. Rép. des Sci.
   2023/009.*