Fisheries and Oceans Canada | Pêches et Océans Canada
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Pacific Region

Canadian Science Advisory Secretariat
Science Response 2024/013

# APPLICATION OF THE BRITISH COLUMBIA SABLEFISH (*ANOPLOPOMA FIMBRIA*) MANAGEMENT PROCEDURE FOR THE 2024-25 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 an MP are defined based on specified management objectives. Performance statistics are compiled during simulation testing of candidate MP options, where each statistic summarizes a fishery outcome related to a specific 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.

The Sablefish MP calculates a recommended catch limit, which has been 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 collect annual abundance and landings data and apply the selected MP to those data in order to calculate the MP catch limit for the upcoming fishing year. Deviation from the selected MP should be avoided since conclusions about MP acceptability based on simulation results are predicated on adherence to the MP. However, the MP may be revised when OM scenarios are updated based on new information, or when 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 monitoring data.

DFO Fisheries Management has requested that Science Branch evaluate the MP response to updated stock and fishery data and resulting harvest advice for 2024-25. This Science Response applies the Sablefish MP to data updated to the end of 2023. The resulting MP catch limit informed the TAC for the 2024-25 fishing year. This document also provides background on the Sablefish 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). The coastwide Sablefish stock in BC has been prescribed under the Fish Stocks provisions (FSP) of the Canadian *Fisheries Act* (*Fisheries Act* R.S.C., 1985, c. F-14, as amended by Bill C-68, June 21 2019). Alignment of the Sablefish management system with the FSP and the DFO PA Policy is achieved via the Sablefish MSE process.

This Science Response Report results from the regional peer review of January 26, 2024 on the Application of the Sablefish Management Procedure in British Columbia for 2024-2025.

# Background

## BC Sablefish Management Strategy Evaluation

The iterative Sablefish MSE process consists of:

1. setting or modifying fishery objectives in response to policy requirements, desired stock conditions, and socio-economic goals;
2. identifying candidate management procedures (MPs) that are feasible to implement;
3. evaluating the performance of those MPs against uncertain stock and fishery dynamics represented within the OM using simulation modelling; and
4. selecting an MP for annual application to the fishery.

MPs consist of a specified set of data, stock assessment method, and harvest control rule that provide 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.

Rather than focusing solely on optimal yield, MSE 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 by considering multiple hypotheses represented by operating models (OMs) rather than focusing on a single 'base case' assessment model. This is accomplished by integrating results over a range of operating models that represent various hypotheses for stock and fishery dynamics. An acceptable means of setting fishing limits is identified by evaluating the simulated performance of alternative MPs against operational fishery objectives and choosing one to apply to the actual 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. Once an MP is selected, it is applied annually until the next round of OM update and MP evaluation.

### 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. 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 in 2022 (DFO 2023) were:

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). Performance metrics are calculated for each simulation replicate, and the expected performance for a management procedure is summarized by the mean (or median) of 100 replicates of each simulation. 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 towards 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. The year 2052 has been retained for 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) have 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). Stock status of BC Sablefish relative to reference points was updated at that time.

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 include trap fishery CPUE (1979-2009), a standardized trap survey (Std; 1990-2009), and a stratified random trap survey (StRS; 2003-2021). Age composition data are used for both the Std. and StRS surveys as well as the Sablefish trap fishery, while length composition data are used for the trawl fishery.

As part of the most recent OM update, environmental variables (EVs) potentially affecting BC Sablefish population dynamics were examined via pairwise correlations between eight EVs, annual recruitment, and a body condition index (DFO 2023, Johnson et al. In press). None of the EVs were strongly correlated to recruitment. While the impact of climate change on BC Sablefish is unknown, recent research indicates that increasing temperature may increase habitat suitability for Sablefish (English et al. 2022). The potential risk of not including EVs into the BC Sablefish OM or MP was assessed as low in 2022 (DFO 2023), but should continue to be assessed as new research emerges.

**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. Each year of the simulation includes 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 Canadian *Fisheries Act*, 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 used by DFO to support evaluations of 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 2022 using data to the end of 2021 (DFO 2023, Johnson et al. In press). 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 historical time series from the OM (1965–2021) characterize a consistent decline in spawning stock biomass between 1965 and 2008 (Figure 1). During this period, occasional years of relatively strong recruitment led to brief periods of stabilized biomass. However, high catch levels and harvest rates that were frequently above the harvest rate at 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 1).

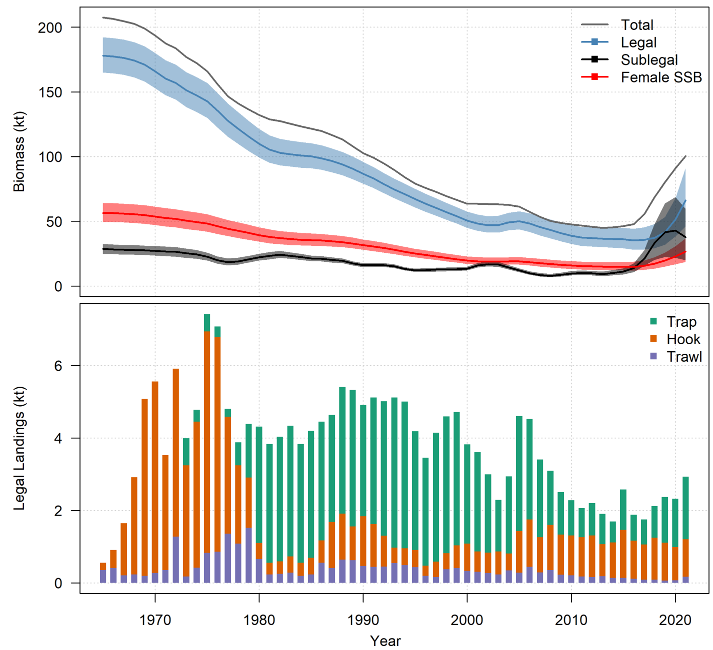


*Figure 1. Top row: Time series of total biomass, legal-sized biomass, sub-legal-sized biomass, and female spawning biomass (SSB) estimates based on weighted averages over the five OM scenarios used in 2022. Note that total, legal, and sub-legal biomass estimates include both female and male fish, while SSB is shown for only female Sablefish. Bottom row: total legal-sized Sablefish landings from each gear type. Figures reproduced from DFO (2023).*

For Sablefish, stock status is estimated using the ratio of female spawning biomass, $B$, to each fishery reference point. For example, status in year $t$ relative to the LRP is defined as $B_t/0.4B_{MSY}$. A value greater than 1 indicates that $B$ exceeds the LRP. Uncertainty in the estimate is communicated by stating the probability that $B$ exceeds $0.4B_{MSY}$, e.g., $P(B > 0.4B_{MSY})$ = 0.98 indicates a very high (98%) probability that female spawning biomass exceeds the LRP.

The most recent revision to the OM estimated 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 29% below $U_{MSY}$ ($P(U_{2021} < U_{MSY})$ = 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 0.8$B_{MSY}$. 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

1. updating input data to include 2023 catch landings and the 2023 catch per unit effort (CPUE) index from the annual Sablefish stratified random trap survey;

2. fitting a state-space surplus production model (SSPM) to the updated dataset to generate an SSPM estimate of biomass;

3. applying a HCR using SSPM estimates of operational control points and biomass to output a catch limit; and

4. 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 2024-25, which includes a maximum target harvest rate of 6.4%. The MP described below was selected based on simulated performance relative to the suite of Sablefish objectives.

## 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 (Lacko et al. 2021). 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). The StRS survey has relatively tight confidence intervals (Figure 2; 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 prep[1]).

In 2023, the StRS mean survey index was 36 kg/trap, which is 10% less than the 2022 value but still in line with the above-average levels seen since 2018 (Figure 2). The 2023 survey index is the fifth highest in the 21-year time series that started in 2003.

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 5). CPUE continued to be highest in the shallow and mid-depth strata in 2023 as the 2016-2017 year classes occupy that habitat; however, there were fewer sets with very high CPUE (>100 kg / trap) in 2023 compared to the last few years.

The 2023 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 36 kg/trap for 2023 was lower than the value of 40 kg/trap seen last year due to a lower number of fish being caught (Appendix Figure 6). However, the mean weight of individual Sablefish caught in 2023 was higher than seen since 2018. 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 2023 was similar to values observed over the previous three years, although the 2023 distribution had less positive skew than observed in 2022, indicating fewer sets with very high CPUE values (Appendix Figure 6).

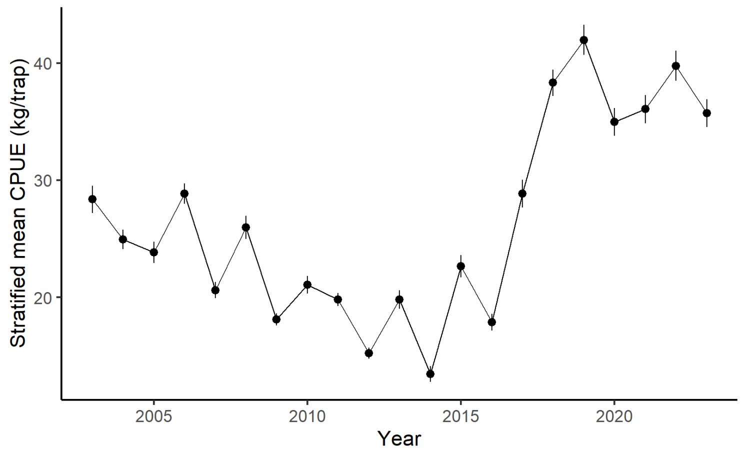


*Figure 2. Estimated coastwide Sablefish biomass index from the stratified randomized survey (StRS) over time, shown as the stratified mean CPUE (kg / trap, shown as points) and 95 confidence interval (error bars).*

Landings of legal-size Sablefish were also updated as part of the MP application. A total landed catch of 3,297 tonnes was used for the 2023 calendar year based on reported catch as of January 3, 2024. Small adjustments of this value can be expected as data are finalized. Reported landings are assumed known due to 100% dockside monitoring of all Groundfish sectors.

## 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 implemented using Template Model Builder (Kristensen et al. 2015) and documented in Johnson et al. (In press).

Annual biomass estimates by the SSPM, $B'_t$, are shown in Figure 3. This biomass differs from the female spawning biomass $B_t$ estimated by the age-structured OM and used for status determination. The SSPM estimate of biomass for 2023, $B'_{2023}$ is 47,808 tonnes, which is only slightly higher than the biomass estimate for 2022 of $B'_{2022}$ = 47,752. 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 six years, a behaviour expected from the Sablefish SSPM based on previous evaluations of its behaviour 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.

## 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 4). 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.

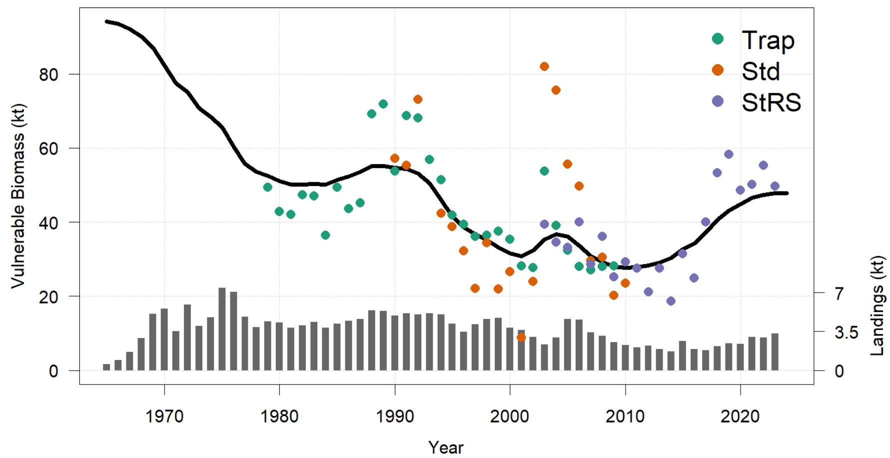


*Figure 3. Total BC Sablefish landings (bars), scaled abundance indices (points), and MP-estimated Sablefish biomass from the SSPM model (black line). Abundance indices have been scaled by estimated catchability for the three different abundance indices used to fit the SSPM model: trap fishery CPUE (Trap), the standardized survey series (Std), and the stratified random survey series (StRS).*

The HCR is defined by the recti-linear function:

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

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 2024-25 Sablefish MP applies a $U_{max}$ of 6.4%. The SSPM estimated biomass for 2024 is well above the estimated upper OCP of 0.6$\hat{B}'_{\text{MSY}}$, which means that the target harvest rate $U_t$ prescribed by the HCR (i.e., using equation 1) is $U_{max}$ = 6.4% (Figure 4).

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 $Q'_{2024}$, based on $U_{2024}$ = 6.4% and $\hat{B}'_{2024}$ = 47,808 tonnes is 3,060 tonnes.

## 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:

$$Q_t = \begin{cases} Q'_t & Q'_t - Q_{t-1} \geq 200 \\ Q_{t-1} & 0 < Q'_t - Q_{t-1} < 200 \\ Q'_t & Q'_t - Q_{t-1} \leq 0 \end{cases} \quad (2)$$

where $Q'_t$ is the catch limit output by the HCR, $Q_{t-1}$ is last year's TAC, and $Q_t$ is the final 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 (row 1 of equation 2), otherwise last year's TAC is taken as the MP catch limit (row 2 of equation 2). There is no constraint on catch limit decreases (row 3 of equation 2).

Because the catch limit $Q'_t$ for 2024-25 is only 31 tonnes higher than the previous year's TAC of 3,029 tonnes, the post-HCR adjustment from equation 2 keeps the 2024-25 catch limit at last year's TAC. The MP catch limit for 2024-25 is therefore 3,029 tonnes.

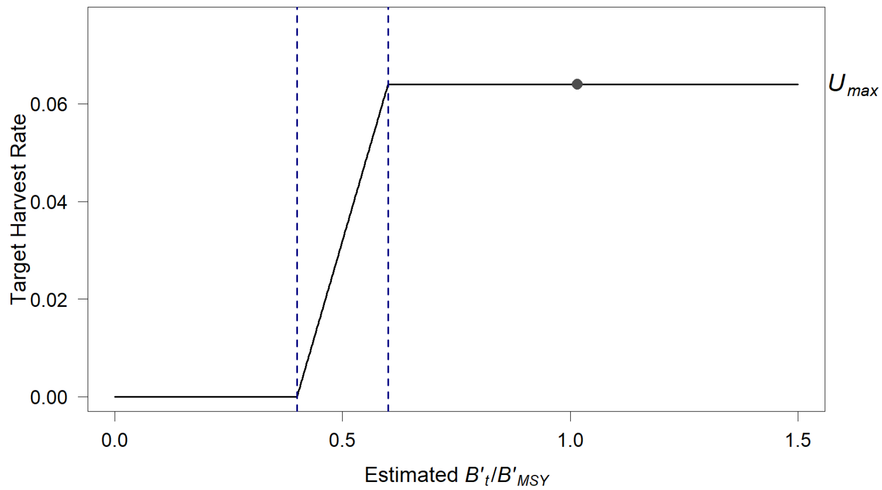


*Figure 4. Sablefish harvest control rule (HCR; solid line) showing the target harvest rate as a function of maximum harvest rate $U_{max}$ and the estimated biomass from the SSPM model component of the MP relative to the SSPM estimate of $\hat{B'_{MSY}}$. Operational control points occur at the SSPM estimates of 0.4$\hat{B'_{MSY}}$ and 0.6$\hat{B'_{MSY}}$ (vertical dashed lines). Forecasted 2024 biomass from the SSPM model (black point) is shown on the HCR.*

# Conclusions

## Precaution in Sablefish MP Selection and Application

Sablefish management in BC meets key requirements identified for precautionary and sustainable fisheries management. These include (i) specific objectives for abundance and fishing pressure, (ii) systems that measure catches and abundance, (iii) rules that determine how catches should be adjusted in relation to stock and fishery monitoring data, (iv) monitoring of fishing pressure and enforcement management actions, and (v) feedback control via application of a simulation-tested MP that adjusts fishing pressure in response to the assessments of stock trajectory (Hilborn 2002; Hilborn et al. 2015).

Specific objectives used to inform the selection of the Sablefish MP (Requirement i, above) 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 applied hierarchically 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 iii, 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, the MP catch limit can be provided every year, without having to do a “full stock assessment”. Even for a year where MP data are missing, it is possible to apply the MP to generate a catch limit. However, consistent loss of MP inputs would require intervention to identify a new MP based on data actually available, or simulation testing of MP response to repeated occurrences of missing data.

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 Sablefish MP used to inform catch limits for the 2023-24 fishing year was based on evaluation over five operating model 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. This same MP is applied to provide advice for 2024-25 in keeping with the desire to consistently apply the same catch limit calculation over time.

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 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 2023. The StRS abundance index for 2023 was 36 kg/trap, which is a decrease of 10% from 2022. However, the SSPM estimate of biomass continued to increase as it has over the past few years. The rate of increase in estimated SSPM biomass was smaller in 2023 compared to the previous few 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 2024/25 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 2026 and 2028. Stock status will be updated at that time and the performance of the existing MP and alternatives re-evaluated via simulation testing.

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February 15, 2024

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# 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 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 | |
| 2023-24 | 6.4 | 6.4 | 3029 | 3029 | OM and MP revised (DFO 2023a, 2023b; Johnson et al. in revision[1]) |

*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)<br>Simulation-tested Management Procedure (MP, defined below) for annual TACs consistent with objectives (defined below)<br>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<br>* Limit Reference Point: LRP = 0.4$B_{MSY}$<br>* Upper Stock Reference: USR = 0.8$B_{MSY}$<br>* 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)<br>Standardized trap survey (1990-2009)<br>Stratified random trap survey (2003-2023)<br>Landings (1965-2023) |
| b. Assessment method | Schaefer state-space production model (SSPM) fitted to data described in (a) above |
| c. HCR | Recti-linear shape with two SSPM-estimated control points:<br>* Lower control point: LCP = 0.4$B_{MSY}$<br>* Upper control point: UCP = 0.6$B_{MSY}$<br>Removal reference:<br>* 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 (Johnson et al. in press). |
| | While the impact of climate change on BC Sablefish is also unknown recent research indicates that increasing temperature may increase some aspects of habitat suitability for BC Sablefish (English et al. 2022). |
| Objectives: | 1) $P(B > B_{LRP}) \geq 0.95$: Maintain female spawning biomass above the limit reference point of $LRP = 0.4B_{MSY}$ in 95% of years measured over 2 Sablefish generations |

| Component | Description |
|---|---|
| | 2) $P(decline)$: When female spawning stock biomass is between 0.4$B_{MSY}$ and 0.8$B_{MSY}$, limit the probability of decline over the next 10 years from very low at 0.4$B_{MSY}$ to moderate (50%) at 0.8$B_{MSY}$. 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 | 2.96 | - | - | 39.756 |
| 2023 | 3.30 | - | - | 35.733 |

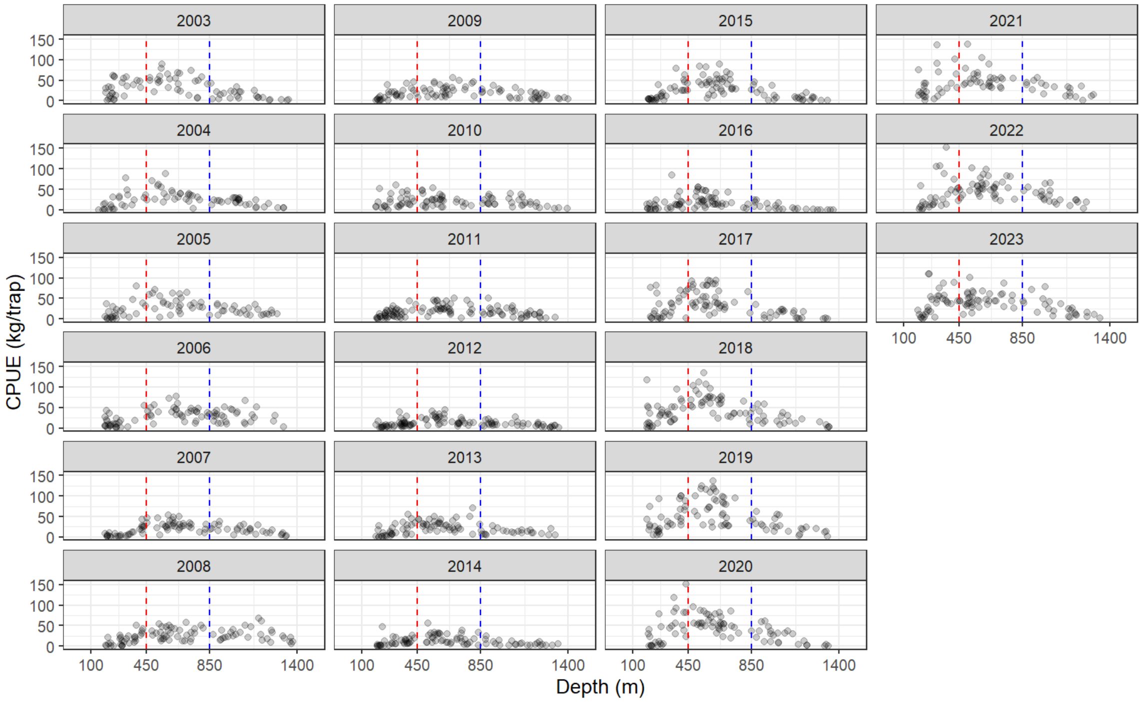


*Figure 5. Sablefish catch per unit effort (CPUE) by depth and year. Dashed lines delineate depth strata (shallow = 100-450m, mid = 450-850m, deep = 850-1400m).*

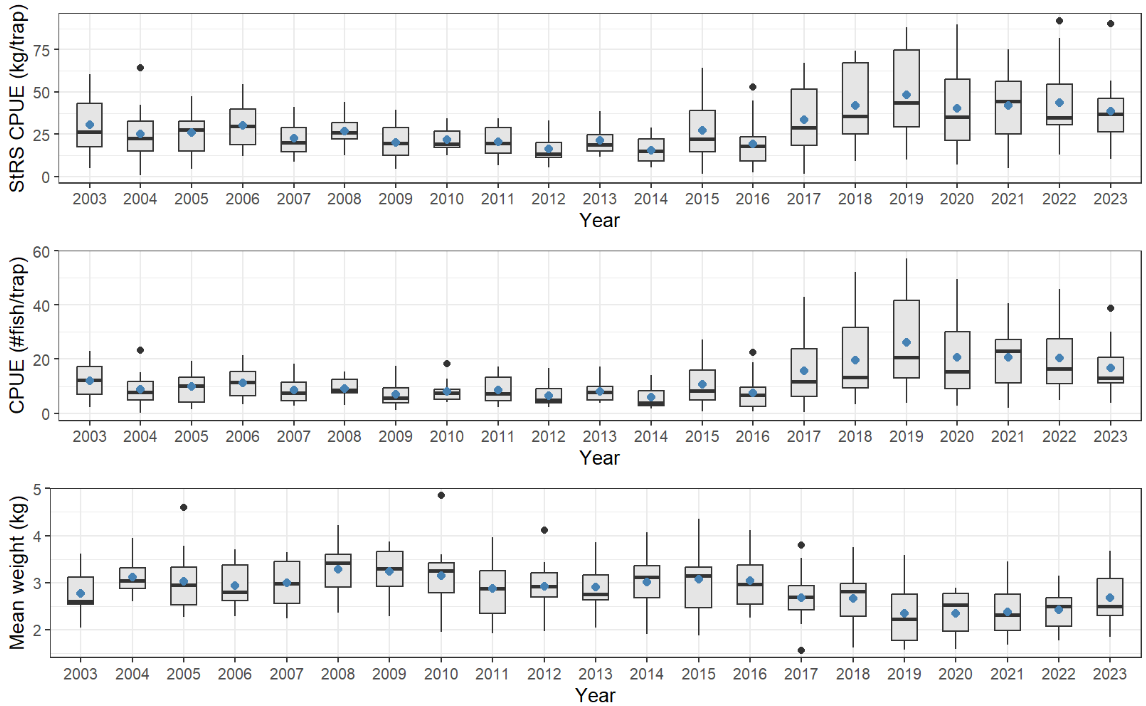


*Figure 6. Top: Annual mean weight of Sablefish per trap (kg/trap); Middle: annual mean number of Sablefish per trap (fish/trap); Bottom: annual mean weight of Sablefish (kg) by StRS survey strata over time. For each year, the horizontal line is the median of the data, the upper and lower hinges of boxes correspond to the first and third quantiles (25th and 75th percentiles), the whiskers extend to the maximum/minimum value up to no more than 1.5 of the inter-quantile range, black dots show data outside of the whiskers, and blue dots are arithmetic mean.*

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ISSN 1919-3769
ISBN 978-0-660-70431-9 Cat No. Fs70-7/2024-013E-PDF


Correct Citation for this Publication:

DFO. 2024. Application of the British Columbia Sablefish (*Anoplopoma fimbria*) Management Procedure for the 2024-25 Fishing Year. DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/013.

*Aussi disponible en français :*

*MPO. 2024. Application de la procédure de gestion de la morue charbonnière (*Anoplopoma fimbria*) de la Colombie-Britannique pour l'année de pêche 2024-2025. Secr. can. des avis sci. du MPO. Rép. des Sci. 2024/013.*