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PROPOSED CANDIDATE HARVEST STRATEGY FOR BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

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SUMMARY

This document presents the IATTC staff's proposed candidate harvest strategy for bigeye tuna in the EPO as requested in paragraph 43 of Resolution C-24-01. The strategy is based on the best available scientific information, considering the management objectives, stock and fishery dynamics, the performance of the stock assessment model, as well as elements collected from IATTC Management Strategy Evaluation (MSE) workshops and lessons learned from MSEs of other stocks, particularly Pacific bluefin tuna. Implementation of the proposed harvest strategy is expected to have the following benefits:

- Reduced purse seine closure days and elimination of the *corralito* (expressed as options to consider under paragraph 14 of Resolution C-24-01);
- Increased longline catch and catch rates for bigeye (associated with higher spawning biomass);
- Increased spawning biomass levels for bigeye;
- Incorporation of the WCPFC limit reference point in the HCR ($S_{20\%}$ as a HCR control point);
- Includes safeguards to avoid biomass levels that might cause substantial reduction in recruitment;
- A 3-year management cycle provides stability in effort and catch of tropical tunas.

The proposed Harvest Control Rule (F_{30}-S_{20}) is shown below, and its main features include:

- F_{max} is set at the level corresponding to Harvest Strategy objective ($S_{30\%}$) to ensure that biomass fluctuates close to that level;
- F is reduced when biomass falls below the WCPFC limit reference point ($S_{20\%}$) to support stock rebuilding, while enhancing catch and effort stability;
- The maximum allowed change in closure days is limited to 10 days between management cycles to reduce variability in effort and catch of tropical tunas.

Several exceptional circumstances are defined to ensure stock and fishery sustainability, including additional actions to be taken when limit reference points are exceeded, understanding of the stock or fishery dynamics changes, data or the ability to conduct stock assessments become compromised, one or more stock status indicators fall outside their historical ranges, or any of the other two tropical tuna species require stricter management (yellowfin or skipjack), among others.

The full specification of the harvest strategy is provided in **Appendix E**.

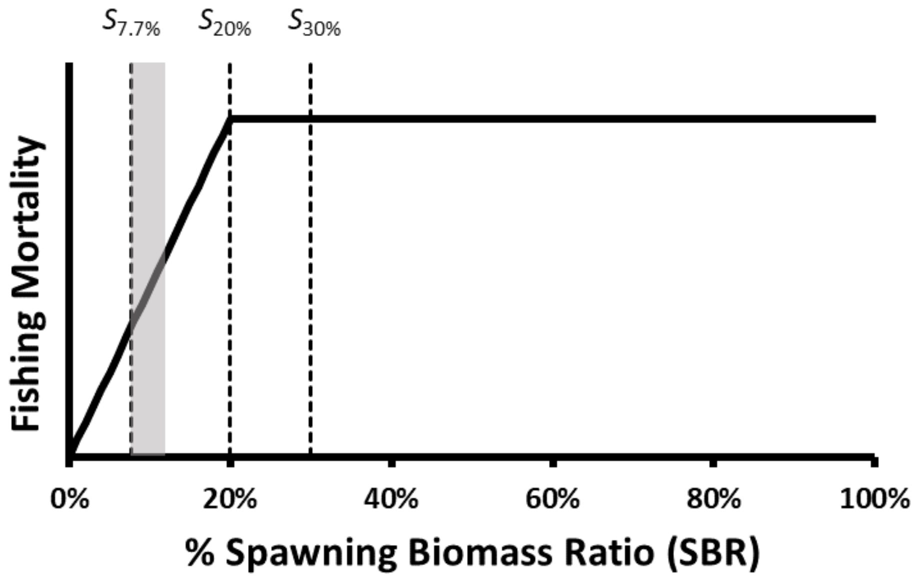

FIGURE S-1. The Harvest Control Rule (F_{30}-S_{20}) in the candidate Harvest Strategy. The shaded area to the right of the limit reference pointy indicates that the exceptional circumstance is based on a 10% probability of breaching the limit, so the expected value of SBR when this occurs is higher than the limit.

1. INTRODUCTION

The implementation of MSE-tested harvest strategies for tuna fisheries is steadily growing as tuna Regional Fisheries Management Organizations (tRFMOs) fulfill their mandates to ensure the long-term sustainability of tuna stocks across the world's oceans (see Document WSMSE-04-01). Harvest strategies (also referred to as management procedures) are completely specified integrated combinations of agreed upon data inputs, analyses applied to that data and the harvest control rule used to determine specific management actions (e.g., catch quotas, length of fishing seasons) to achieve management objectives. It is important to note the difference between a harvest control rule (HCR) and a harvest strategy (HS). A HCR provides a prescription for management measures (e.g., fishing mortality as a function of spawning biomass), while a HS includes several components in addition to a HCR.

The IATTC is in the process of developing formal harvest strategies for tropical tunas in the eastern Pacific Ocean (EPO), beginning with the development of a harvest strategy for bigeye tuna. Several elements of a harvest strategy for tropical tunas have already been adopted by the IATTC, such as an interim harvest control rule (HCR) and reference points, amended recently to include proxy reference points. However, some elements may need to be refined (e.g. specificity of management objectives, such as probability of being above target reference points) and other elements have yet to be adopted (e.g. type, duration and derivation of management actions, and definition of exceptional circumstances) to constitute a formal harvest strategy. Furthermore, a full Management Strategy Evaluation (MSE)—which includes the ongoing dialogue component among scientists, managers, and other stakeholders to define the key elements, along with a computer-based simulation testing framework used to assess the performance of multiple candidate harvest strategies against management objectives—still needs to be completed. This process is intended to lead to the adoption of a formal harvest strategy at IATTC (Report of the 4th MSE Workshop).

Meanwhile, Resolution C-24-01 tasks the IATTC staff, consulting with the SAC, to present for the Commission in 2025 a candidate harvest strategy for bigeye tuna. Specifically, according to paragraph 43 of the resolution:

> *The IATTC shall continue efforts to develop harvest strategies for tropical tunas. The IATTC scientific staff shall continue to establish the scientific basis, through Management Strategy Evaluation testing, to advise the Commission on initial candidate harvest strategies, starting with bigeye tuna. The staff, consulting with the SAC, shall then present for the Commission's consideration in 2025 a candidate harvest strategy for bigeye tuna, including candidate management actions to be taken under various stock conditions.*

1.1. Purpose of this document

In response to paragraph 43 of Resolution C-24-01, and in alignment with paragraph 40 (promoting compatibility between the conservation and management measures adopted by the IATTC and WCPFC), this document presents the staff's proposed candidate harvest strategy for bigeye tuna in the EPO. The proposed candidate harvest strategy is based on understanding of the stock dynamics, fishery, and stock assessment, and lessons learned from MSEs of other stocks (WSMSE-04-01), particularly Pacific bluefin tuna. The proposed harvest strategy outlines its key components along with their respective rationales. Technical specification of the harvest strategy is provided in **Appendix B**.

A discussion on reference points is first presented in Section 2, as they are often considered an essential part of harvest strategies but can serve multiple roles, requiring careful consideration and appropriate selection. The individual components of the staff proposed candidate harvest strategy are then presented in Section 3. The technical specification of the harvest strategy is presented in Appendix B. and a chronogram of how the harvest strategy would operate is presented in Appendix C.

2. CONSIDERATIONS ON REFERENCE POINTS IN THE DEVELOPMENT OF HARVEST STRATEGIES

Reference points have become a standard element of fisheries management. They serve as benchmark values used to assess the status of the stock and to guide management decisions. The main reference points are target and limit levels of biomass and fishing mortality. Target Reference Points (TRPs) represent desired levels of biomass or fishing mortality and aim to ensure long-term sustainability of the stock and fishery. Limit Reference Points (LRPs) define thresholds that indicate an undesirable biological state, such as critically low biomass levels that could lead to recruitment failure, which requires immediate management action and should have a very low probability of being breached (UN-FSA).

Reference points are used in various ways, and how they are applied influences how they are defined. In the context of harvest strategy development, reference points are commonly regarded as key elements or components of a harvest strategy. They typically appear as control parameters of harvest control rules, performance metrics, or in defining exceptional circumstances. However, reference points do not necessarily have to be explicitly used in harvest strategies.

Limit reference points need specific consideration when used in harvest strategies since they are generally defined (e.g., UN-FSA) as levels for which there should be a very low probability of exceeding. A harvest strategy could be chosen using MSE which, from performance metrics, has a low probability of exceeding the limit reference point. In this case the limit reference point is not used as part of the control rule, it is used to define a performance metric. This is completely independent of whether the estimation model has determined that the stock has exceeded the limit reference point. The complication with including a limit reference point as part of the harvest control rule is that a probability statement cannot be used, such as in the IATTC's current harvest strategy [$P(S < S_{0.77\%}) < 10\%$], because it would be impractical to test using MSE. Therefore, it is more feasible to include a probability statement about exceeding the limit reference point, estimated by a stock assessment (risk analysis), as an exceptional circumstance. In addition, the harvest strategy should be designed to avoid the limit reference point and therefore, if it has been determined to have been exceeded with a low probability, this indicates that the stock dynamics or fishery may be in a state that was not tested in the MSE or the estimation model is compromised. More analyses and reconsideration of the harvest strategy is prudent, as would be specified in the exceptional circumstances.

Below are examples of how reference points are used and concepts that should be taken into account when developing a harvest strategy for bigeye tuna in the EPO.

- **Stock status**: In tuna fisheries worldwide, it is important to categorize stocks by their exploitation status (e.g., overfished or subject to overfishing) for various purposes including stock status summaries (e.g. Kobe plots) and compliance with fishery certification and ecolabeling programs (e.g. MSC certification). Traditionally, MSY-related quantities have been used to define reference points for these categories. However, whether such reference points are considered targets or limits, and whether they apply to overfished conditions or overfishing, has evolved over time. In the context of harvest strategy development, the management targets (i.e., objectives) do not necessarily need to align with those used to define stock status. Moreover, the reference points used to determine stock status may differ from those that control the shape of the harvest control rule (e.g., how fishing mortality changes with biomass). In other words, reference points are not always the control parameters in the HCR.
- **Management action:** Exceeding a reference point is often a trigger for management action and can be considered as part of an informal or formal harvest strategy. For example, the IATTC has traditionally implemented fishing closures aimed to achieve the target F_{MSY} and set the closure

length in days based on stock assessment estimates of the current fishing mortality (F_{cur}) relative to F_{MSY}. The IATTC incorporated this approach into its *informal* harvest strategy (C-23-06) as well as mandating a rebuilding plan when the limit reference points are exceeded with a 10% probability. In a *formal* harvest strategy, exceeding a limit reference point may be treated as an exceptional circumstance that prompts a predefined management response.

- **Harvest control rules (HCRs):** Harvest control rules typically define maximum levels of fishing mortality or catch and specifically how fishing mortality or catch should be reduced as biomass declines. Intuitively, incorporating reference points into an HCR helps drive the stock toward target levels and away from limits. However, the HCR may not perform exactly as intended due to various factors. Additionally, the use of reference points as a HCR's control parameters may be inappropriate when the desired probability of exceeding those reference points differs from 50% or the estimation model (EM) is "biased" with respect to average of the possible alternative states of nature (i.e., the operating models used for testing within an MSE). HCR may have completely independent control points that define the shape of the HCR, and reference points could be used to compute performance metrics.
- **Performance metrics:** Reference points can be used to develop metrics for evaluating the performance of HCRs within a MSE framework. However, the specific definitions of stock status may not necessarily be the objective of management (e.g., the desired biomass may be higher than the overfished level due to economic, social, or ecosystem benefits). Therefore, relevant performance metrics or additional performance metrics may differ from the stock status reference points.

The IATTC needs to define and adopt target and limit reference points in conjunction with defining overfished and overfishing. This should preferably be done before developing the harvest strategy, and they may not necessarily be the same as the objectives used to develop the harvest strategy.

2.1. IATTC interim reference points

The IATTC has adopted interim limit and target reference points (Resolution C-16-02 and its amendment C-23-06):

Limit Reference points: 7.7% of equilibrium virgin spawning biomass ($S_{7.7\%}$; based on a conservative steepness of *h*: 0.75 and 50% reduction in recruitment) and fishing mortality associated with that level ($F_{7.7\%}$).

Target Reference points: based on dynamic S_{MSY} and F_{MSY}. Note that the IATTC scientific staff proposed new proxy reference points for tropical tuna stocks, around $S_{30\%}$ (SAC-15-05), which are consistent with the levels used as proxies for skipjack.

The target and limit reference points are used in the IATTC's interim HCR for tropical tunas (Resolution C-16-02 amended by C-23-06):

Target:

"*The scientific recommendations for establishing management measures in the fisheries for tropical tunas, such as closures, which can be established for multiple years, shall attempt to prevent the fishing mortality rate (F) from exceeding the best estimate of the rate corresponding to the maximum sustainable yield (FMSY) for the species that requires the strictest management*."

Limit:

"*If the probability that F will exceed the limit reference point (FLIMIT) is greater than 10%, as soon as is practical management measures shall be established that have a probability of at least 50% of reducing F to the target level (FMSY) or less, and a probability of less than 10% that F will exceed FLIMIT.*"

"*If the probability that the spawning biomass (S) is below the limit reference point (SLIMIT) is greater than 10%, as soon as is practical management measures shall be established that have a probability of at least 50% of restoring S to the target level (dynamic SMSY) or greater, and a probability of less than 10% that S will descend to below SLIMIT in a period of two generations of the stock or five years, whichever is greater.*"

2.2. Harmonization with WCPFC reference points

The development of a harvest strategy for the tropical tuna in the EPO should take into account the IATTC's intention to move toward compatibility with measures adopted by WCPFC, as expressed in the spirit of Resolution C-24-01, specifically in paragraph 40:

> *The IATTC shall continue efforts to promote compatibility between the conservation and management measures adopted by the IATTC and WCPFC in their goals and effectiveness especially in the overlap area, including by frequent consultations with the WCPFC, in order to maintain, and inform their respective members of, a thorough understanding of conservation and management measures directed at bigeye, yellowfin, and other tunas, and the scientific bases and effectiveness of those measures.*

The WCPFC has defined limit reference points for all three tropical tuna species, but only interim target reference points. The target reference point for skipjack is the average of two biomass depletion levels (roughly equivalent to 50 percent of the estimated recent average spawning potential in the absence of fishing), and those considered for bigeye and yellowfin are based on historic biomass levels. The limit reference point for all three stocks correspond to 20 percent of the estimated recent (last 10 years) average spawning potential in the absence of fishing (MSE-04-01).

It is premature to discuss harmonization of target reference points across the two RFMOs in this document, however, there may be an opportunity to harmonize limit reference points. The IATTC defines its limit reference points as a biomass level, or associated fishing mortality level, that is expected to cause a large reduction in recruitment and is at a level that should be breached with very low probability. However, since many tuna stocks have declined below $S_{20\%}$ at some point in their history without catastrophic reduction in recruitment, the WCPFC limit may serve a different purpose. The WCPFC limit may be more related to definitions of overfished and overfishing, while the IATTC limit is where drastic management action should be taken. These are two different definitions and uses of limit reference points as discussed in the introduction of Section 2.

2.3. Use of reference points in the interim harvest strategy

Here we discuss the reference points in relation to the harvest strategy and leave definitions in relation to stock status to a different discussion. Target reference points are discussed in SAC-15-05 and $S_{30\%}$ and $F_{30\%}$ are proposed based on a more global definition of MSY taking into account the selectivity of different gear types and the possibility of a stock-recruitment relationship.

In terms of using limit reference points to determine the shape of the HCR, considering the $S_{20\%}$ limit as a stock size that is undesirable, but not catastrophic, $S_{20\%}$ is used as a control point for the HCR when fishing mortality decreases. Whereas the IATTC limit reference point of $S_{7.7\%}$ is used as an exceptional circumstance where additional strict management action (e.g. a rebuilding plan) needs to be taken when there is a 10% probability the limit has been breached.

> **"Reference" points for use in the HS:**
> **HS Objective:** $S_{30\%}$
> **HCR Fmax:** $F_{30\%}$
> **HCR control point:** $S_{20\%}$
> **Exceptional circumstances limit:** $P(S < S_{7.7\%}) \geq 10\%$

3. PROPOSED CANDIDATE HARVEST STRATEGY FOR BIGEYE TUNA

Contemporary best practices in fishery management involve selecting harvest strategies through extensive testing using Management Strategy Evaluation (MSE). However, because MSE is a computationally intensive process, limitations in time and computational resources restrict the number of alternative harvest strategies that can be evaluated. As a result, to make the process more efficient, the staff believes HCRs, along with the estimation model (EM) and other components of the harvest strategy, should be developed using the best available science before testing their ability to meet management objectives. This process draws on existing knowledge of the system, stock assessment methods, and insights gained from MSEs conducted on other fisheries. By evaluating the performance of the bigeye tuna assessment, incorporating lessons from other tuna MSEs, particularly that of Pacific bluefin tuna, and applying robustness concepts, the staff proposes a candidate harvest strategy for bigeye tuna in the EPO. In the sections that follow, each component of the harvest strategy is outlined along with the rationale behind its selection.

3.1. Type of strategy: Model-based

The objectives of the harvest strategy (e.g., maintaining stock status around the target reference point) are more complex than generally what can be achieved using simple empirical indicators (e.g., maintaining constant abundance or achieving a specific CPUE). Therefore, a model-based approach using a population dynamics model similar to the full assessment is employed.

3.2. Management cycle: 3 years

Maintaining consistency in the management over a 3-year period provides stability to the fishery. A 3-year cycle has been used previously by the IATTC and is also employed by other t-RFMOs.

3.3. Management objectives

Understanding and specifying management objectives is essential to ensure that the harvest strategies developed will meet their intended goals. Identifying these objectives in advance of full MSE testing, during which performance metrics are defined and harvest strategies are evaluated, helps ensure that candidate strategies are aligned with those objectives. This approach reduces the likelihood of testing ineffective strategies and, given the computational demands of MSE, increases the number of meaningful strategies that can be evaluated. Defining the management objectives is the purview of the Commission, but since they have yet to be defined, objectives were interpreted from several sources to identify them such as the Antigua Convention, Resolutions, and the IATTC MSE workshop discussions.

General objectives are defined in Article VII (c) of the IATTC's Antigua Convention, which states:

…adopt measures that are based on the best scientific evidence available to ensure the long-term conservation and sustainable use of the fish stocks covered by this Convention and to maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield…

Clearly, this implies that a minimum objective is to ensure that biomass remains at or above the level that produces maximum sustainable yield (MSY). However, defining MSY can be complex. For example, MSY is dependent on the assumptions of selectivity, which is complicated to define given historical changes in the catches of fishing fleets with very different selectivities (e.g. before the mid 1990s most of the BET catches were taken by longline consisting of adult bigeye, while after the 1990s most of the BET catches are taken by purse-seine consisting of juvenile BET). This objective, although not always explicitly stated, also implies a corresponding fishing mortality objective. Additional objectives often relate to catch or effort levels, sometimes in reference to historical benchmarks, as well as stability in catch or effort, and the avoidance of low biomass levels that could impair recruitment (e.g., the IATTC limit reference point of $S_{7.7\%}$). These objectives align with those discussed by stakeholders during the IATTC MSE workshops (Table 1).

Under the current management measures for tropical tuna in the EPO, purse-seiners that catch large amounts of bigeye (exceeding IVT levels) in floating-object sets are penalized with additional closure days. As a result, bigeye tuna is regarded as an "undesirable" or "bycatch" species for these vessels, making high catches of bigeye tuna in the purse seine fishery not a target objective. However, high catch may be a target for distant water longline fisheries, which have historically targeted bigeye in the EPO. Since the longline fishery primarily catches adult bigeye, the catch in this fishery is linked to the level of spawning biomass. Therefore, an objective for spawning biomass can also support the objective of longline catch. However, the spawning biomass at S_{MSY}, based on current age-specific fishing mortality and stock assessment model assumptions, is relatively low (median SBR of 22.2%, SAC-15-02), only slightly above the LRP of $S_{20\%}$ used at WCPFC. Therefore, a biomass target above this level might be more appropriate. The IATTC staff has previously recommended $S_{30\%}$ as an alternative proxy for the interim target reference point (SAC-15-05). It should be noted that the tropical tuna purse seine fishery is a multi-species fishery, and high catches of skipjack and yellowfin would be an objective for the Commission, which is related to the objective of reducing the days of closure.

Since bigeye tuna has been the species requiring the strictest management measures among the three tropical tunas, reducing fishing mortality for bigeye would allow for a reduction in the seasonal closure of the purse-seine fishery. In paragraph 14 of Resolution C-24-01, the IATTC staff is explicitly requested to consider reductions in the closure of the purse-sein fishery due to reductions in fishing mortality on bigeye tuna resulting from the current measures. Therefore, reducing the closure of the purse-seine fishery is an objective that should be considered. Similarly, Resolution C-24-01 explicitly requests the IATTC staff to consider the elimination of the *corralito*, implying its elimination should be considered as an objective.

Clearly, catch and effort stability and reducing the closure are incompatible objectives in the short term. Therefore, the stability objective discussed at the workshops may need to be clarified, modified, or evaluated on a medium- to long-term basis.

Stock assessment estimates of quantities relative to historical levels are generally more reliable than stock assessment estimates of absolute values or those relative to reference points. Therefore, objectives based on historical values may be useful for developing robust harvest strategies. The IATTC staff defined a *status quo* period (2017–2019) for monitoring the purse-seine fishery to ensure that fishing mortality for bigeye tuna did not increase. An alternative reference period could be 2019–2021, which corresponds to the highest fishing mortality estimates for bigeye tuna prior to the implementation of the IVT measure which contributed significantly to reduction in F for juvenile bigeye.

The following is a list of objectives interpreted by the staff to have been clearly stated at the MSE workshops, in the Convention or Resolutions, or other sources:

Objectives:

Maintain stock at or above $S_{30\%}$: $S \geq S_{30\%} \geq S_{MSY}$
Maintain stock above limit RP with very high probability: $S >> S_{7.7\%}$
Maintain F below reference level: $F \leq F_{2019\text{-}2021}$
Long term stability of catch and effort
Reduction in the closure of the purse-seine fishery
Elimination of the *corralito*

3.4. Harvest control rules

The staff harvest control rule (F_{30}-S_{20}) proposed for the candidate harvest strategy is based on the following concepts that guided its development:

1. The HCR should be simple and designed to achieve the management objectives;
2. Fishing at the rate corresponding to the target biomass will cause the biomass to fluctuate around that target. This assumes the assessment model reliably estimates fishing mortality and that the objective to maintain biomass fluctuating around the target, rather than to ensure a high probability (e.g. 75%) of remaining above it. If the latter is desired, multiple $\boldsymbol{F_{max}}$[1] levels would need to be tested or the HCR would have to be tuned accordingly, both of which increase the computational demands of the MSE. Therefore, the HCR sets the $\boldsymbol{F_{max}}$ at the level corresponding to the biomass target $F_{30\%}$;
3. Fishing at a mortality rate corresponding to the biomass target, even when the biomass is below the target, will still drive the biomass toward the target.
4. Action should be taken before a limit reference point is exceeded to prevent the sudden implementation of restrictive management measures. Therefore, fishing mortality should be reduced before reaching the limit.
5. A biomass control point that is too close to the target biomass may result in higher catch variability.
6. Management actions should not change abruptly (e.g., the number of days that the seasonal closure can change between management cycles should be limited).
7. At low biomass levels (near the limit reference point), management actions should be guided by exceptional circumstances, not the HCR. This is because the HCR is designed to keep the biomass away from these levels and when the stock is evaluated to be at these levels it is likely that the stock or fishery dynamics is different than tested in the MSE, or the EM is not performing correctly. Note that the HCR may have to be specified for all levels of biomass to facilitate MSE testing.
8. Fishing mortality should not exceed historically observed levels.

[1] F_{max}: upper limit on the fishing mortality rate (F) that can be applied to a stock under the HCR framework. It serves as a cap to prevent excessive exploitation, even when the stock biomass is above target levels.

3.4.1. The F_{30}-S_{20} HCR

1- Fishing mortality specified by the HCR (F_{HCR}) remains constant at F_{max} = $F_{0.30\%}$ until the dynamic (the unexploited biomass is calculated using the time series of historic recruitment) spawning biomass ratio (SBR) reaches $S_{20\%}$, after which it declines linearly to zero as the SBR approaches zero (**Figure 1**).

2- F_{max} is set at the level corresponding to target reference point ($F_{0.30\%}$) to ensure that biomass fluctuates close to the management objective.

3- F is reduced when biomass falls below $S_{20\%}$ to support stock rebuilding. The HCR control point ($S_{20\%}$), being below the target, is intended to enhance catch and effort stability. It is also equal to the LRP used by the WCPFC.

4- The maximum allowed change in management action (closure days) is limited to 10 days to reduce variability in catch and effort, and to prevent adverse outcomes. 10 days is approximately 15% of the current closure. Other tRFMOs have used 15% as a maximum change. Note that this is not a change in the F as F is proportional to the days open.

5- Fishing mortality is calculated based on the average of the most recent three years in the estimation model (EM, see Section 3.5.), consistent with the current approach to minimize biases in recent year estimates and to smooth out random fluctuations.

Harvest Control Rule: F_{30}-S_{20}

F_{MAX}: $F_{30\%}$
$S_{control}$: dynamic $S_{20\%}$
$S_{F=0}$: 0
Maximum allowed change (closure days): 10 days

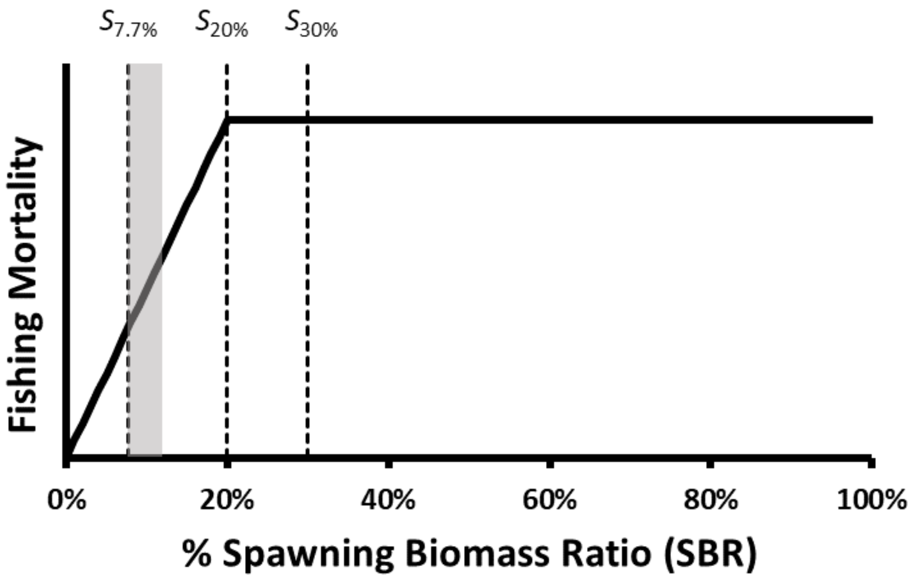

FIGURE 1. Proposed harvest control rule for the bigeye tuna candidate harvest strategy in the EPO and its relationship to the HS objective ($S_{30\%}$), HCR maximum fishing mortality ($F_{max} = F_{30\%}$), HCR control point ($S_{20\%}$) and exceptional circumstance limit reference point ($S_{7.7\%}$). %SBR is the percentage Spawning Biomass Ratio, spawning biomass divided by the spawning biomass in the unfished state. The shaded area to the right of the limit reference pointy indicates that the exceptional circumstance is based on a 10% probability of breaching the limit, so the expected value of SBR when this occurs is higher than the limit. The HCR objective and control point are based on dynamic S_0, while the limit reference point is based on equilibrium S_0, so the x-axis is inconsistent. However, we have included them all on the same x-axis for illustrative purposes.

3.5. Estimation model (EM):

The choice of estimation model in the proposed candidate harvest strategy is guided by several key principles:

1. The full assessment model is too computationally intensive for extensive MSE testing, therefore a simpler model is needed.
2. The estimation model (EM) should retain the key features of the full assessment model to ensure reliability and robust performance under untested circumstances. Since the longline CPUE based abundance index represents adult fish, while the bigeye catch is primarily composed of juveniles, an age-structured model is required.
3. The EM must accurately estimate fishing mortality for the life-stages targeted by the HCR (i.e. juveniles).
4. Estimates of abundance and fishing mortality should not be highly sensitive to the addition of new years of data (e.g., the biomass trajectory should not be substantially rescaled with the addition of new data points, and retrospective patterns should remain minimal).
5. Assessment models for tropical tunas that do not incorporate recruitment variability generally fail to adequately estimate absolute abundance when fitted to indices of abundance.

6. Catch should be removed at approximately the correct size of fish. If composition data are not used in the model, the assumed selectivity and estimated fishing mortality rates should not result in predicted size compositions substantially different from those observed.

The simplest form of assessment model that incorporates age-structure is the Age-Structured Production Model (ASPM), which accounts for the age of fish caught by each fishery. For bigeye tuna, the ASPM generally does not estimate unrealistically high levels of abundance, unlike its application for other stocks such as EPO yellowfin tuna (SAC-16-03). Unfortunately, it does not provide a good fit to the abundance index. To improve the fit to the index, the ASPM can be extended to include recruitment variation (ASPM-Rdev). However, the ASPM-Rdev estimates of absolute abundance for many of the bigeye reference models is low (Figure A4 in SAC-15-02) due to high estimated fishing mortality. This high fishing mortality allows for the model to explain changes in the index of abundance with variation in recruitment, but it also leads to a predicted catch composition dominated by unrealistically small fish, a pattern similarly observed in the EPO yellowfin tuna assessment. To address this, and following the approach used for Pacific bluefin tuna, the EM includes some length composition data (ASPM-Rdev+, where the "+" indicates it uses some length composition data). Specifically, it includes length composition data for the abundance index (which assumes dome-shape selectivity) and for the longline fishery (which assumes asymptotic selectivity) and estimates their selectivities.

Current management advice is based on a risk assessment using an ensemble of models with different assumptions. However, in a Management Strategy Evaluation (MSE), it is not feasible to use an ensemble of models as the estimation model (EM). Ensembles are instead used for the operating models and a single model needs to be chosen as the EM. The assumptions of the base reference model are therefore used for the EM.

Robustness tests conducted in the Pacific bluefin MSE, showed that the ASPM-Rdev+ EM performed poorly under scenarios involving regime shifts in recruitment. This is primarily because a large amount of catch consists of small fish, and the EM lacks direct information about recruitment, resulting in biased estimates of recent fishing mortality. Ideally, an EM would include information on small fish; however, there is currently no reliable index of juvenile bigeye tuna abundance, and the composition data from the floating object fisheries is currently considered unreliable for informing juvenile abundance. While estimates of fishing mortality from the EM may be biased and imprecise, the scaling factor required to adjust current fishing mortality to achieve $F_{30\%}$ is generally both precise and unbiased (**Table 1**). It is also worth noting that effort-based management through the implementation of seasonal closures, as implemented for the tropical tuna in the EPO, is considered more robust to changes in recruitment and assessment uncertainty than catch-based management, such as that used for Pacific bluefin tuna. Therefore, accurate estimates of juvenile fishing mortality may be less critical for EPO bigeye tuna (Squires et al., 2016).

TABLE 1. Estimation error in the adjustment required to achieve $F_{30\%}$ was evaluated for EPO bigeye tuna through a retrospective analysis using both the full assessment model and the EM (ASPM_Rdev+) proposed in the harvest strategy. Estimates from the full assessment model using the complete dataset were treated as the "truth," and estimates generated by systematically omitting consecutive recent years of data were compared against these to assess estimation error. Fishing mortality was calculated using a three-year average, consistent with the standard approach for providing management advice in the bigeye tuna assessment and as defined in the proposed harvest strategy.

Year	Full assessment	ASPM_Rdev+
2018	-4%	-6%
2019	8%	4%
2020	6%	3%
2021	-1%	-1%
2022	1%	5%

Estimation model (ASPM-Rdev+):

Age structured production model
Estimated recruitment
Fit to a subset of the length composition data
Base reference model assumptions

Data used:
Catch by fishery
Longline CPUE: Spatiotemporal standardized index of abundance
Length composition: Longline index and fishery

3.6. Management actions

Tropical tunas in the EPO are currently managed through a combination of temporal closures for purse seine vessels, catch limits for longline vessels, and bigeye tuna Individual Vessel Thresholds (IVT) for certain fleet components. Additional measures include limits on fleet capacity, full retention requirements, limits on active FADs, and a spatial closure (the *corralito*). Effort controls are generally preferable for tropical tunas, which exhibit variable recruitment. Therefore, implementing the HCR through fishing closures is the most appropriate approach. Although the IVT program introduces complexity into the relationship between *F* and the closure, the application of the HCR will adjust for the IVT over time. The duration of the fishing season (or more accurately, the number of open days = 365 – closure days) is modified in proportion to the ratio of the fishing mortality from the harvest control rule to the current fishing mortality (F_{HCR}/F_{cur}), where F_{cur} is based on the three most recent years. The number of closure days should continue to be adjusted for any increases in fleet capacity (the ratio of the existing capacity to the new capacity, C_{old}/C_{new}). The elimination of the *corralito* in 2026 is being considered by the Commission (paragraph 14 of Resolution C-24-01), and if eliminated does not need to be included in the calculations. It is likely that the introduction of the IVT program may have introduced some non-linearity in the relationship between fishing mortality and the length of the opening, and that the relationship may no longer be directly proportional; fishing mortality is likely to increase at a slower rate than the increase in open days. However, as noted above, the estimation model (EM) used in the HCR framework will gradually adjust to this nonlinearity over time.

Management actions (calculation of PS closure days):

$Closure_{new} = 365 – (365\text{-}Closure_{old})(F_{HCR}/F\text{cur})(C_{old}/C_{new})$

3.7. Exceptional circumstances

Exceptional circumstances are identified to ensure that factors not covered under the harvest strategy do not cause irreparable harm to the stock or fishery. If exceptional circumstances are triggered, the existing management measures shall remain in force, or management reverted to the 2025 levels, where specified, until new management measures are implemented, or other actions are agreed upon by the Commission. The following exceptional circumstances have been identified:

1. If the IATTC limit reference point is breached with a probability greater than 10% based on the risk analysis from a full (update or benchmark) assessment, a rebuilding plan will be developed in accordance with that specified in paragraph 3.c. under Resolution C-23-06. The stock must be rebuild within two generations. The age at 50% maturity of bigeye tuna is about three years, assuming twice this represents two generations, rebuilding must occur within six years.
2. If the fishing mortality from the harvest control rule (F_{HCR}) exceeds the average F over the three years prior to the introduction of the IVT (2019-2021, denoted $F_{2019\text{-}2021}$), then the current fishing mortality (F_{cur}) relative to $F_{2019\text{-}2021}$ will be used to determine the duration of the closure (i.e., $F_{2019\text{-}2021}$ is substituted for F_{HCR}). This ensures that F does not exceed historical values.
3. If a full assessment (update or benchmark), an updated MSE based on operating models (OMs) using the new full assessment, or one or more stock status indicators fall outside their historical range and suggest that the current harvest strategy is no longer appropriate, the harvest strategy will be re-evaluated. Benchmark assessments are conducted on a regular schedule, but may also be triggered if there are substantial changes in fishing operations or in the understanding of stock biology. If necessary, a new MSE will be conducted to determine an updated harvest strategy.
4. A harvest strategy specifies the data required to implement or evaluate the HCR. The loss of any critical data would invalidate the harvest strategy and thus constitutes an important exceptional circumstance.
    a. The Enhanced Monitoring Program (EMP) is an integral component of the IVT management measures, which have been crucial in improving the recent stock status of bigeye tuna. It needs to be maintained to ensure the HS is effective. If the EMP program (or its proposed alternative IPSP, SAC-16-06) is not maintained or the IVT is evaluated as

ineffective, the harvest strategy will be re-evaluated, including the possibility of reverting management measures to 2025 levels.

   b. If the longline CPUE index of abundance (or other data used in the EM) is deemed unreliable, the entire harvest strategy will need to be re-evaluated, including the potential need for a new benchmark assessment and MSE.

5. If the closure resulting from the application of the HCR exceeds 72 days, alternative measures, implemented in addition to the 72-day closure, will be considered. Given the effectiveness of the IVT, the closure is expected to be reduced from the 72 days, but changes in the stock biology or fisheries may require a longer seasonal closure requiring reconsideration of the type of management measure.
6. If the longline catch exceeds its TAC then the catch of the longline fishery is re-evaluated.
7. If a benchmark stock assessment for either of the other two tropical tuna stocks (yellowfin or skipjack) indicates that one of these other stocks requires stricter management measures than set by the bigeye harvest strategy, management will be based on that stock.
8. The objective of reduced seasonal closure days will increase fishing mortality on skipjack tuna. Therefore, an assessment of skipjack tuna is necessary to ensure that reduced closure days guided by the bigeye harvest strategy do not compromise its sustainability and without a reliable stock assessment management will revert to 2025 levels. A reliable assessment cannot be conducted without new tagging data and a tagging program needs to be initiated in 2026.

Exceptional circumstances:

- The IATTC limit reference point is exceeded with a probability greater than 10%
- F_{HCR} is greater than the 2019-2021
- When a benchmark assessment, MSE, or indicators suggests the HCR is inappropriate
- Data becomes unreliable
- The EMP program (or its proposed alternative, the IPSP) is not continued or the IVT is evaluated to be ineffective
- The purse seine closure resulting from application of the HCR is more than 72 days
- Either yellowfin or skipjack requires stricter management
- Longline catch exceeds its TAC
- A reliable skipjack tun assessment is not available

3.8. Considerations for other tropical tuna species (yellowfin and skipjack)

The current interim HCR (Resolution C-23-06) will continue to be applied to yellowfin and skipjack and evaluated through periodic assessments. If the *F* under the current HCR for either of these species requires a longer closure than that determined for bigeye, the more conservative *F*, and corresponding closure duration, will be applied.

The HCR for each species will be updated as additional information, such as the results of Management Strategy Evaluation (MSE), becomes available for each species. The staff does not recommend changes to the management measures currently specified in Resolution C-24-01, including implementation of the proposed candidate harvest strategy outlined in this document, unless a reliable skipjack tuna assessment is available. This will depend on a tagging program being initiated in 2026.

3.9. Management Strategy Evaluation (MSE)

Best practice for managing fish stocks involves using Management Strategy Evaluation (MSE) to test harvest control rules. However, because MSE is a computationally intensive process, and many components of the harvest strategy and MSE have yet to be agreed upon by the Commission, completion of the MSE for bigeye has not yet been possible. As a result, it is necessary to rely on the best available science to develop an candidate harvest strategy for bigeye tuna. In 2025 and 2026, MSE should be used to test the proposed candidate harvest strategy and compare it with alternative strategies to select a formal and fully tested harvest strategy (planned to be discussed at the 5th IATTC MSE workshop and the 1st Meeting of the IATTC MSE workshop on May 30 and 31, respectively).

In addition to the harvest strategy components proposed above, conducting an MSE requires several additional elements, which are briefly discussed below. Input on these components has been gathered through IATTC MSE workshops facilitated by staff, which have included open dialogue with various stakeholders (see WSMSE-04 RPT). This dialogue process was recently strengthened through Resolution C-24-08, which established an IATTC ad hoc working group to enhance communication among scientists, managers, and other stakeholders on Management Strategy Evaluation (MSE). The first meeting of this working group is to take place on May 31, 2025. This meeting could be used to define the remaining elements necessary for the staff to test the proposed candidate harvest strategy and alternatives, enabling the completion of the bigeye MSE in 2026.

3.9.1. Performance metrics

Harvest strategies are evaluated using MSE. Performance metrics are developed to evaluate their performance to meet the management objectives. Table A.1 in Appendix A lists alternative performance metrics that were discussed at recent IATTC MSE workshops. Since different stakeholders may have different objectives, and multiple ways to measure those objectives, performance metrics are not intended to be prescriptive in selecting harvest strategies, and some overlap among them is expected. However, the set of performance metrics must remain limited and focused to support effective decision-making. In addition to selecting the appropriate metrics, it is essential to present them in formats that are accessible and easily understood by stakeholders.

3.9.2. Operating models

Harvest strategies are tested through MSE by applying them under different assumptions about the stock and fishery dynamics. These assumptions are represented by the operating models (OMs). The OMs should be selected to ensure that the chosen harvest strategy performs well across a range of alternative *states of nature* (hypotheses) that are considered likely for the stock (reference set of OMs) and, ideally, also be robust to *states of nature* that are plausible (robustness set of OMs), but unlikely. For bigeye tuna in the EPO, the stock assessment models comprising the ensemble used in the risk analysis will be used as the operating models (SAC-15-02, SAC-15-07). This ensemble represents the reference set and includes 33 model configurations that vary in assumptions related to individual growth, fishery selectivity (asymptotic or dome-shaped), the steepness of the Beverton-Holt stock recruitment relationship (h values: 1.0, 0.9, 0.8), natural mortality for adults males (M values: 0.1, 0.12, 0.125, 0.13), and three rates of annual increase in longline catchability (0%, 1%, 2%). A robustness set with natural mortality, growth and selectivity assumptions from the previous (SAC-11) benchmark stock assessment has been considered (WSMSE-04 RPT).

Appendix A

Table A.1. Objectives, quantities and performance indicators (collected during IATTC MSE workshops; WSMSE-04_RPT).

OBJECTIVE	**Quantity (desired levels)**	**Performance Indicators**
Safety *Maintain stock above limit reference points*	*Equilibrium virgin spawning biomass S_0* B_{lim}: $P[SB < 7.7\%S_0] < 10\%$ F_{lim}: $P[F > F_{7.7\%\ So}] < 10\%$	Probability calculated over projected 30 years (All years, any year by replicates) Ratio of S_{yr}/S_0 Ratio of $F_{yr}/F_{7.7\%\ So}$
Status Maintain stock in green quadrant of Kobe plot	SB ≥ dynamic dSB_{MSY} and $F \leq F_{\text{MSY}}$, *60% probability*	% of simulated runs falling in Kobe's green quadrant Probability calculated over projected 30 years (All years, any year by replicates)
Stability Maintain low variability of catch and effort limits, gradual changes in management measures. Caps at 10% (effort), 15% (catch)	Standard deviation of annual catch, effort Average interannual proportional change (catch, effort)	% change in catch and/or effort between years Calculated over projected 3, 15 and 30 years
Yield/Abundance Maintain catches/effort/CPUE above historical ranges	Average catch/effort/CPUE by fishery (PS and LL) • *2017-2019 (latest status quo)*	Ratio of projected 3, 15 and 30-year average catch/effort/CPUE by fishery over historical period
Status quo Maintain the stock at levels near the (2017-2019) status quo	Spawning biomass, Index (LL CPUE)	Ratio of projected 3, 15 and 30-year average SB, Index (LL CPUE) over status quo period (2017-2019)

Appendix B. Detailed specification of the harvest strategy

The HCR will be applied every three years and the management will be set for three years.

Harvest strategy HS-F_{30}-S_{20} has three types of data input: catch for all fisheries, a longline CPUE index of abundance, and length composition for one longline fishery (area 4 – central tropical) and for the index of abundance. The fisheries, method to standardize the CPUE data, and the methods to create the catch and length composition data are described in SAC-15-02. An age-structured production model (ASPM-Rdev+) conducted using Stock Synthesis based on the base reference model from SAC-15-02 is fit to the index of abundance and composition data. All the selectivity curves, except for the index and one longline fishery (area 4 – central tropical), biological parameters, and data weighting are fixed based on the base reference model of SAC-15-02. Estimated parameters are virgin recruitment, recruitment deviates (the first quarter of 1979 – the last quarter of the last year with data), initial fishing mortalities for one longline and one floating-object purse-seine fishery, selectivity for the index (the first four parameters of the double-normal selectivity), selectivity for the one longline fishery (the first and third parameters of the double-normal selectivity). From these parameters the key variables used in the harvest control rule are derived:

> SBR_{cur}: the spawning biomass in the start of the year after the last year data is available divided by the dynamic unexplored biomass calculated using the historic trajectory of recruitment.
>
> F_{HCR}/F_{cur} where the calculations are based on the average age-specific fishing mortality in the most recent three years that data is available for.

The HCR is applied based on SBR_{cur} from the EM

$$F_{HCR} = \begin{matrix} 1.5SBR_{cur} & SBR_{cur} < S_{20\%} \\ F_{30\%} & SBR_{cur} \geq S_{20\%} \end{matrix}$$

The days of closure are calculated based on the old closure adjusted for F_{HCR} and any change in fishing capacity with a maximum change of 10 days:

$$Closure = 365 - (365 - Closure_{old})\left(\frac{F_{HCR}}{F_{cur}}\right)\left(\frac{Capacity_{old}}{Capacity_{new}}\right)$$

$$Closure_{new} = \begin{matrix} max[Closure_{old}, Closure] & Closure < Closure_{old} - 10 \\ min[Closure_{old}, Closure] & Closure > Closure_{old} + 10 \end{matrix}$$

Where $Capacity_{old}$ is the average fishing capacity in well volume over the three years used to define F_{cur} and $Capacity_{new}$ is the capacity at the start of the following year.

Exceptional circumstances

If exceptional circumstances are triggered, the existing management measures shall remain in force, or management reverted to the 2025 levels, where specified, until new management measures are implemented, or other actions are agreed upon by the Commission.

1. If the IATTC limit reference point (equilibrium $S_{7.7\%}$) is breached with a probability greater than 10% based on the risk analysis from a full (updated or benchmark) assessment, a rebuilding plan will be developed in accordance with that specified in paragraph 3.c. under Resolution C-23-06.

   As soon as is practical management measures shall be established that have a probability of at least 50% of restoring S to the target level (dynamic $S_{30\%}$) or greater, and a probability of less than 10% that S will descend to below the limit reference point (equilibrium $S_{7.7\%}$) in a period of 6 years.

2. If the fishing mortality from the harvest control rule (F_{HCR}) exceeds the average F over the three years prior to the introduction of the IVT (2019-2021, denoted $F_{2019\text{-}2021}$), then the current fishing mortality (F_{cur}) relative to $F_{2019\text{-}2021}$ will be used to determine the duration of the closure (i.e., $F_{2019\text{-}2021}$ is substituted for F_{HCR}).

$$Closure = 365 - (365 - Closure_{old})\left(\frac{F_{2019-2021}}{F_{cur}}\right)\left(\frac{Capacity_{old}}{Capacity_{new}}\right)$$

3. If a full assessment, an updated MSE based on operating models (OMs) using the new full assessment, or one or more stock status indicators fall outside their historical range and suggest that the current harvest strategy is no longer appropriate, the harvest strategy will be re-evaluated. If necessary, a new MSE will be conducted to determine an updated harvest strategy.
4. If the EMP program (or its proposed alternative IPSP, SAC-16-06) is not maintained or the IVT is evaluated as ineffective, the harvest strategy will be re-evaluated, including the possibility of reverting management measures to 2025 levels.
5. If the longline CPUE index of abundance (or other data used in the EM) is deemed unreliable, the entire harvest strategy will be re-evaluated, including the potential need for a new benchmark assessment and MSE.
6. If the closure resulting from the application of the HCR exceeds 72 days, alternative measures, implemented in addition to the 72-day closure, will be considered.
7. If the longline catch exceeds its TAC then the catch of the longline fishery is re-evaluated.
8. If a benchmark stock assessment for either of the other two tropical tuna stocks (yellowfin or skipjack) indicates that one of these other stocks requires stricter management measures than set by the bigeye harvest strategy, management will be based on that stock.
9. If a reliable assessment is not available for skipjack tuna, management reverts back to the 2025 levels.

Appendix C. Chronogram

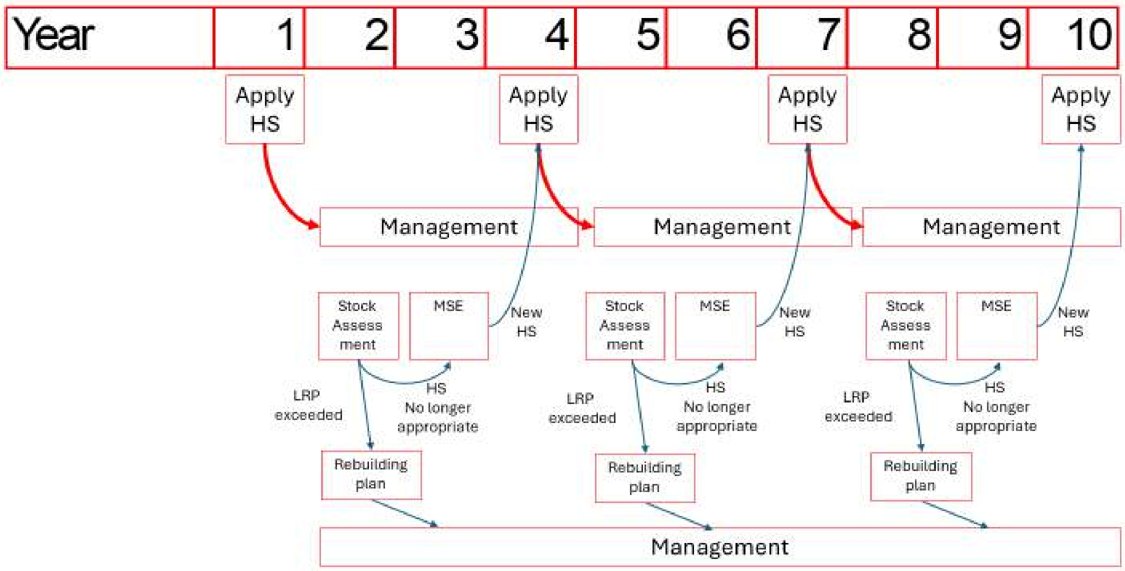

FIGURE C1. Chronogram of the harvest strategy. The harvest strategy has several exceptional circumstances. These are expected to be rare events, so they are not shown on the chronogram. Some exceptional circumstances are evaluated every year, others are only evaluated when the harvest strategy is evaluated, or when the full stock assessment or MSE is conducted. Several of exceptional circumstances can initiate a new full stock assessment and MSE. In this case a new harvest strategy would be selected and applied, and the chronogram would re-start in year 1. Similarly, when the limit reference point has been triggered and the stock rebuilt, the chronogram would re-start in year 1.