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TROPICAL TUNA HARVEST STRATEGIES IN THE EASTERN PACIFIC OCEAN

Juan L. Valero, Mark N. Maunder and Alexandre Aires-da-Silva

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1. INTRODUCTION

Management strategies (often referred as harvest strategies, 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. Harvest strategies can be evaluated using a process called Management Strategy Evaluation (MSE), involving a dialogue component between scientists, managers and other stakeholders along with computer simulation of candidate strategies. Harvest strategies have been increasingly and widely used both nationally and internationally, including by all five regional fisheries management organizations for tuna (t-RFMOs: IATTC, IOTC, WCPFC, ICCAT, CCSBT) which are in different stages of development and implementation with CCSBT the furthest along with a successful MSE development, testing and implementation of a management procedure already in place and with IATTC at the earliest stage in the process.

Fisheries for tropical tunas in eastern Pacific Ocean (EPO) ranged around 500 to 830 thousand tons since the year 2000, representing almost 14% of the world's production of tuna and around 1.7 billion US$ ex-vessel value in 2012. Management advice for EPO tropical tunas in the IATTC has traditionally been based on a 'best assessment' approach, recently incorporating a multi-model risk assessment when available. At present, the three tropical tuna species, bigeye (BET), yellowfin (YFT) and skipjack (SKJ), are assessed via formal stock assessment models. Previously, the IATTC staff concluded that their BET (2018) and YFT (2019) stock assessments were not reliable to be used as the basis to provide management advice. Although Stock Status Indicators (trends in catch, CPUE, etc.) produced for the three species are often used in support of the assessments, they are not operationalized for example in a harvest control rule (HCR) to link them to specific management actions. When lacking reliable assessments there is no currently quantitative default process to provide management advice. The assessments were improved resulting in new benchmark assessments in 2020, but several uncertainties remain. To overcome issues with current assessments for BET and YFT, the staff proposed in 2020 a weighted multi-model risk analysis that considers parameter and assessment model structure uncertainty. Incorporating assessment uncertainty in the management advice is an improvement over the previous approach, allowing the evaluation of probability statements included in the current HCR. However, the IATTC staff recognizes ongoing unresolved issues in the understanding of the stocks that can have large management implications for the combined species tropical tuna fishery, which is managed based on the species needing the strictest management (BET in recent history, see Figure 1 of SAC-15-07). The staff proposed two venues to address ongoing issues and to improve management advice: 1) improving stock assessments and 2) continuing ongoing MSE for tropical tunas (one of the main goals of the IATTC Strategic Science Plan).

The IATTC has adopted elements of a harvest strategy for tropical tunas such as interim 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, probability of being above target reference points) and other elements added (e.g. type, duration and derivation of management actions) to constitute a complete strategy and its evaluation. Initial simulation testing work of a simplified HCR was conducted in 2016 and 2018 and substantial progress has been made on developing operating models, however a proper MSE process requires a complete specification or alternative strategies to evaluate, for which the input and participation of managers and other stakeholders is desired. Although there are no dedicated, formal communication channels on MSE (such as a Working Group) within the IATTC, SAC meetings and dedicated workshops provide opportunities for dialogue, communication, and training on MSE. There have been requests by stakeholders for the establishment of a dedicated dialogue Working Group, which could enhance or replace the IATTC staff organized MSE workshops. Recommendations during SAC-14 stated that the Commission consider the Science-Management Dialogue (SMD) or informal workshops approach to continue the MSE process. Introductory workshops on harvest strategies and MSE were held in Panama (2015) and the United States (2018), aimed at managers, and a further five 1-day educational workshops, aimed at the tuna industry, took place during 2019 in Colombia, Ecuador, Mexico, Panama, and USA. In 2019, Resolution C-19-07 acknowledged the IATTC staff MSE workplan and set the basis and terms of reference for IATTC MSE workshops. Three workshops have been held part of the 2018-2023 MSE workplan. The 1st IATTC sponsored MSE workshop (on objectives and performance metrics) was held in person in December 2019. The 2nd IATTC sponsored MSE workshop (on reference points and harvest control rules) was held virtually during 2021. The 3rd IATTC tropical tuna MSE workshop was held (also by videoconference) at the end of 2022. These workshops have been conducted with the support of the European Union.

This document describes harvest strategy elements already adopted at the IATTC, outlines elements in need of refinement or in need of adoption. It is not intended to be an exhaustive review but instead a

living document that can be updated as development of harvest strategies, their evaluation and adoption continues at IATTC.

2. MANAGEMENT OF TROPICAL TUNAS IN THE EPO

2.1. MANAGEMENT OBJECTIVES

General objectives are defined in IATTC's Antigua Convention's Article IV (c) stating *"to ensure the long-term conservation and sustainable use of the fish and to maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield"*.

In order to have a more completely specified harvest strategy, generic objectives need to be converted into operational objectives expressed in terms of the values of performance statistics (Punt et al, 2016). Operational objectives include performance metrics, probabilities and timeframes that allow to evaluate how alternative harvest strategies perform using MSE. Part of the challenges in specifying management objectives is that the tropical tuna fishery in the EPO is a mixed stock fishery (BET, YFT and SKJ often co-occur during fishing operations), has multiple gears (purse-seine, longline) and operates using multiple fishing modes (dolphin-associated, non-associated, floating object). Other challenges include historical and ongoing changes in the distribution of the catches between different fleets that catch fish of different sizes and ages, which affects the overall pattern of fishing mortality and therefore the resulting MSY over time (SAC-15-05). The approach has been to manage the tropical tuna fishery based on the species (BET, YFT, SKJ) which requires the strictest management (historically BET), with management actions mostly based on input controls (mainly fishing effort in the way of days of closure for the purse-seine fishery, limits on fishing capacity and recent BET Individual Vessel Thresholds (IVT), with catch limits for the longline fishery, and other measures, see section on Management Measures). Progress has been made during the series of IATTC MSE Workshops into developing more specific objectives (Table 1) as part of the ongoing MSE for tropical tunas, which has focused initially on bigeye tuna. The staff is recommending additional workshops in 2024 and 2025 to further refine objectives and other harvest strategy elements, along with their evaluation. Examples from harvest strategies other tuna RFMOs are provided.

2.2. PERFORMANCE MEASURES

Performance measures are related to the quantities of interest to evaluate how alternative strategies are able to achieve management objectives. Although no performance measures have been outlined in the Resolutions related to HCR (C-16-02, C-23-06), in general, the informal performance of the HCR appears to have been based on stability (i.e. maintaining the same management measures such as days of closure), keeping the fishery open for as long as possible, and total catch. These are standard performance measures for most fisheries. Table 1 outlines some of the performance measures that have been informally discussed during IATTC MSE workshops.

2.3. REFERENCE POINTS

Reference points can be used for multiple purposes including to determine the status of the fishery, as performance measures, and as components of harvest control rules (HCR). In the context of tropical tunas in the EPO, the IATTC has used reference points for all of these purposes both formally, as adopted by resolutions (C-16-02, C-23-06), and informally through operational usage (see Table 1 of SAC-15-05). Interim limit and target reference points were adopted by the IATTC at its 87th Annual Meeting. IATTC Resolution C-23-06 includes the use of target proxy reference points due to the difficulty in defining MSY-based reference points for skipjack tuna.

2.3.1. LIMIT REFERENCE POINTS

Limit reference points (LRP) were adopted, on an interim basis, at the IATTC in 2014 following the staff's recommendation of setting the LRP at the equilibrium spawning biomass/fishing mortality corresponding to that which produces an expected 50% reduction in recruitment from the equilibrium unfished level (assuming a conservative level of the steepness of the stock-recruitment relationship h=0.75). This corresponds to a spawning biomass that is about 0.07 of the unfished spawning biomass level.

2.3.2. TARGET REFERENCE POINTS

Target reference points (TRP) were adopted at the IATTC in 2014 on an interim basis both in terms of the fishing mortality (F_{MSY}) and spawning biomass (S_{MSY}) corresponding to the maximum sustainable yield (MSY). Unlike the equilibrium LRP, TRP are dynamic, that is its calculation considers changes over time in recruitment. Proxy target reference points were adopted in 2023 (Resolution C-23-06) for cases where MSY-based TRP cannot be reliably estimated, or otherwise specified, from parameters estimated within the assessment model. Proxy reference points corresponding to $0.3S_0$ were used for skipjack tuna for the first time in the 2022 stock assessment. Staff revisited TRP for tropical tunas in 2024 (SAC-15-05) following concerns about the definition of the target reference point and estimated highly depleted stock levels at MSY ($S_{MSY}/S_0 = 0.17$) for some scenarios of the 2024 bigeye tuna assessment given recent changes in the assumptions about age-specific natural mortality. A more global approach to defining MSY, which is designed to support a range of proportioning of catch among the fleets, supports a less depleted biomass ($S_{MSY}/S_0 = 0.3$). The staff has proposed to consider $S_{MSY}/S_0 = 0.3$ as interim target reference point until discussions under a comprehensive Management Strategy Evaluation framework process determine target reference points based on a variety of objectives (SAC-15-05, SAC 15-07).

2.4. HARVEST CONTROL RULE

Prior to 2016 and the adoption of the HCR specified in IATTC Resolution C-16-02, the operational control rule was essentially fishing at F_{MSY} or, more accurately, reducing the fishing mortality to F_{MSY} if the fishing mortality of either yellowfin or bigeye tuna exceeds its respective F_{MSY}, as estimated by the their respective best (base case) stock assessments (SAC-07-07g). The IATTC provisional HCR for tropical tunas was defined in IATTC Resolution C-16-02 requires action be taken if the probability of the spawning biomass being below the limit reference point is greater than 10% [i.e. $P(S_{current} < 0.077S_0) > 0.1$]. The HCR also requires action to be taken if the probability that the current fishing mortality is above the limit reference point is greater than 10% [i.e. $P(F_{current} > F_{S/S0}=0.077) > 0.1$]. The scientific recommendations for management action, as defined by the HCR, are based on the stock of the three tropical tunas (yellowfin, bigeye, and skipjack) that requires the strictest management. Until 2022, the stock which required the strictest management was based on assessment results for either yellowfin or bigeye tuna, with the condition of skipjack inferred based on having similar susceptibility to the fishery as bigeye but is more productive. In 2022 a skipjack assessment was conducted (the first conventional stock assessment considered reliable by the IATTC staff for use in management advice, SAC-13-07), proxy target reference points were proposed and adopted for skipjack, along with adoption of Resolution C-23-06 which amended the HCR to incorporate the use of proxy reference points.

The HCR currently in use for management of tropical tunas at IATTC explicitly includes the adopted target and limit reference points as 1) the applied fishing mortality rate attempting to prevent F from exceeding the best estimate of the F_{MSY} for the species that requires the strictest management, 2) as probability-based trigger or control points (if the probability that F of S will breach the F_{LIMIT} or B_{LIMIT} is greater than 10%) and 3) rebuilding targets for F (if limit is breached, have a probability of at least 50% of reducing F to the target level or less, and a probability of less than 10% that F will exceed F_{LIMIT}) and S (have a probability of at least 50% of restoring S to the dynamic target level or greater, and a probability of less

than 10% that S will descend to below S_{LIMIT} in a period of two generations of the stock or five years, whichever is greater). For the purpose of designing and evaluating alternative HCRs as part of the ongoing MSE for tropical tunas it may be useful to think in terms of reference points when evaluating the status of stocks or for calculating performance indicators to evaluate the performance of an HCR and to use the terms control points or trigger points to define the shape of the HCR, that is the levels at which management action changes, which may coincide or not with the currently adopted reference points.

In general, management measures related to the HCR have been set on a 3-year cycle, remaining fixed for that period but with the possibility of being adjusted, for example by monitoring stock status indicators, although no mechanisms have been specified to make those adjustments. This cycle follows the assessments cycle, which have been carried out every three years in recent years, as well and provide estimates of the management quantities needed to implement management. However, the periodicity of management measures and assessments has not been formally specified and it has changed, for example when assessments have been considered by the staff to not be reliable for management, or when the Commission does not agree on management measures by consensus, as required by the Antigua Convention. Since actions by default have not been adopted, there are no default management actions that would be taken if the Commission cannot come to an agreement on new conservation measures at the end of a management cycle. This has led to multiple extraordinary meetings in recent years to allow for negotiations to take place to arrive at new conservation measures. Adopting management actions by default, for example by reverting to management actions adopted for the previous cycle if no agreement on new management measures is reached, would remove this type of uncertainty under the current type of management. Under a completely specified harvest strategy, management actions are pre-agreed and specified by the strategy. However, default actions (defined by meta-rules, e.g. conduct a new assessment or revise strategy) still need to be defined for events that fall outside of what the strategy was designed for or evaluated to be robust against (often called exceptional circumstances, e.g. loss of a major data type needed in the strategy, major drop in recruitment).

In summary, the implementation of the HCR is not fully specified, in a harvest strategy sense, and therefore can be open to interpretation or discussions during specification of management measures at IATTC. Some of the elements in need of further specification include the type of and calculation of the magnitude of management measures (e.g. seasonal closures, spatial closures, IVT), consistency of measures among different gears, the data collection and analyses (e.g. specification of assessment) used to produce the HCR inputs, periodicity (e.g. every year, every 3 years) among others. Some of those elements are discussed in the next sections.

3. MANAGEMENT MEASURES

Management measures for tropical tunas in the EPO consist mainly of using temporal closures for purse-seine vessels and catch limits for longline vessels. A review of alternative conservation measures for the purse-seine fishery for tropical tunas in the EPO was conducted recently (SAC-12 INF-B). The main management measure in place is the seasonal closure for purse-seine vessels. The closure can be in one of two periods, July to September or November to January, and can also be adjusted to take into account increases or decreases in fishing fleet capacity. The duration of the closure is calculated as follows:

Closure = 365- F_{MSY}/F * (365-current closure)/(capacity of previous year/previous 3-year average capacity)

Where F_{MSY}/F is the F multiplier, or by how much the fishing mortality would have to be multiplied to achieve F_{MSY} for the tropical tuna stock in need of strictest management, historically since 2002 bigeye tuna (see Figure 1 of SAC 15-07) but occasionally yellowfin tuna (2013, 2015, 2016 and 2017).

An individual vessel threshold program for purse-seine vessels catching bigeye tuna was implemented in 2022 (SAC-15 INF-K). There are additional measures currently in place such as limited entry for new purse-

seine vessels, fishing capacity should remain constant, full retention requirement for all purse-seine vessels regarding bigeye, skipjack and yellowfin tunas and limits on the number of active FADs. There is also a smaller spatial closure ("El Corralito") for purse-seine vessels from 29 September to 29 October within the area from 96° to 110°W between 4°N and 3°S. An evaluation of this closure (SAC-05-16) found that it was equivalent to 3 days of closure for the entire EPO, and therefore the closure calculation above is adjusted for this. A recent re-evaluation of this spatial closure (SAC-15 INF-M) found results consistent with the predicted levels of impact, on average 3 days of closure for bigeye but with substantial year-to-year variation ranging from 14 additional days of closure for BET in some years to an additional 4 days of fishing in others.

The longline fishery is managed using annual catch quotas for bigeye tuna divided among the major longline fishing nations. Although Resolution C-16-02 and its amendment C-23-06 state that management measures shall be as consistent as possible with those adopted for the purse-seine fishery, there is no clear mechanism for the potential adjustment of the longline quotas.

Other measures that have been recommended by the staff but not adopted include combinations of temporal and large spatial purse-seine closures (e.g. 2003, 2004), individual vessel limits on purse seine bigeye catches (e.g. 2003), additional closure days for the floating object fishery catching bigeye (e.g. 2006), limits on the number of floating object and unassociated sets (2018, 2019), limits on the number of floating object sets + individual vessel daily active FADs (2020). Purse-seine catch limits were adopted in 2017 for bigeye and yellowfin for purse-seine fleets operating with FADs and an additional catch limit for yellowfin from dolphin associated fisheries. However, catch limits were abandoned when the FAD fishery reached 80% of the annual catch limit mid-year, reverting back to closures by extending the temporal closure by 10 days (C-17-02). In this regard, effort controls (such as the temporal closures) are a more adaptive way to provide fishing opportunities while preventing unplanned increases in fishing mortality when stock sizes are either overestimated or underestimated, respectively. Effort controls also provide a more flexible way to manage multispecies fisheries such as the tropical tunas, since they can reconcile conservation objectives of two or more stocks when they are based on the most vulnerable stock, historically bigeye in the case of tropical tunas in the EPO.

Ideally, during the implementation of a MSE, the management action (e.g. total catch limit, spatial closure, individual vessel thresholds) should be specifically implemented within the modeling framework. However, this is not always possible for the more detailed management actions (e.g. individual vessel thresholds, active FAD limits). In some cases, the relationship, and its potential bias and variance, between the management action and its impact on fishing mortality may be known approximately and could be used to define the impact of an action and the possible implementation error. The current MSE for BET using the *Stock Synthesis* stock assessment models as operating models and the ability to specifically implement the various management actions is limited. In general, total catch limits and total effort limits (or the seasonal closure with the assumption that the seasonal opening is proportional to the fishing mortality) are the only management actions that are directly implementable in this platform. Various management actions and the relationship with fishing mortality and its potential bias and variance could be implemented to describe total IVTs, spatial closures, OBJ set limits or active FAD limits until a better understanding of the relationship between those management actions and fishing mortality.

4. DATA COLLECTED

There are no data inputs that have been agreed upon to use in management setting for tropical tunas in the EPO. However, similar data have been collected by the IATTC for decades and used in the stock assessments, with other data only recently becoming available (e.g. sonar buoy Indices). The main sources of data are catch and fish length composition by fishing fleet, and indices or relative abundance based on fishery catch-per-unit-of-effort (CPUE) data. These are standard data collected in many fisheries

worldwide. There are other data that are collected and used in the stock assessment and/or used to estimate quantities used by the stock assessment including fish age-length data (e.g. from otoliths) to inform growth, weight-length data, and tagging data to inform natural mortality, individual growth or recently absolute abundance estimates (SAC-15 INF-G). However, despite being important for the assessment, these data are often not collected on a routine basis and difficult to include in the specification of a harvest strategy. The main types of data used in the stock assessments and the auxiliary data have a well-defined precedent. However, the approaches to using the data in the assessment have changed over time based on best available science. For example, the use of longline CPUE data in the assessment has changed from areas as fleets GLM analysis to whole EPO spatial-temporal analysis to create “survey fleets”. There are no fishery-independent surveys of tuna abundance and size composition in the EPO, with the term "survey" in this context referring to a fleet modelled in the stock assessment that has data (e.g., CPUE and size composition) but takes no catch. Although it is often difficult to specify all the data, collection methods, analyses, etc. in a harvest strategy, it is a crucial part of setting a viable strategy. Otherwise, what may seem like an otherwise well specified strategy may lack the ability to be consistently applied over time if data types, collection methods or analyses may change or not be available to be used as an element of the strategy. A recent example in the EPO is the adoption of an Individual Vessel Threshold (IVT) for purse-seine vessels catching bigeye tuna which went into effect in 2022 (SAC-15 INF-K). As part of the IVT program, an enhanced port-sampling program (“Enhanced Monitoring Program”, EMP) for estimation of trip-level BET catch was mandated by Resolution C-21-04, to support member countries and their purse-seine vessels in their conservation efforts. However, in subsequent years there has been uncertainty about the continuation of the EMP, which brings into question the ability to continue the IVT program and therefore its continuation as an element of a strategy.

5. ASSESSMENT OR DATA ANALYSIS

Similar to what was described for the data collected, the assessment method to be used for tropical tunas is not specified. Although the same general type of stock assessment (age-structured catch-at-length analysis) has been conducted by IATTC staff for two decades, the implementation of the assessment models changes based on best available science at the time of each assessment. This includes the software used (e.g. the switch from *ASCALA* to *Stock Synthesis*). The assessment method makes a wide range of assumptions including values of fixed parameters (e.g. natural mortality), functional forms representing processes (e.g. selectivity), what data is used in the model (which indices of relative abundance and/or absolute abundance are used), and how data is fit in the model (e.g. the effective sample size for composition data).

In general, it is difficult to specify all the stock assessment model assumptions unless the assessment is simple. When using a complex assessment with multiple data sets, there is always a possibility that an assumption needs to change to overcome some issue with the assessment or to accommodate a new data type or data analysis. To overcome these issues, it is often the case that when developing and evaluating harvest strategies, stock assessment models take different roles than in a best-assessment approach and separate stock assessment from management, even in harvest strategies that use a stock assessment. Some of those different roles are to use the stock assessment to develop the Operating Models used to evaluate harvest strategies via MSE, explore alternative hypothesis about stock/fishery dynamics, explore the use of new types of data, track long-term status of stock given harvest strategies, check whether Exceptional Circumstances (specified events that fall outside of what has been evaluated in an MSE) have been triggered. Therefore, the type of stock assessment model that is often used to drive management in a harvest strategy framework is much simpler. For example, in the management procedure adopted by the IOTC for bigeye tuna in 2022, the model that drives management is a Pella-Tomlinson state-space model, fitted only to catch and longline CPUE (Hillary et al, 2021). In other cases, empirical approaches

(following simple data analyses such as following CPUE trends) or a mix of empirical and model-based approaches are used. For example, the management procedure for southern bluefin tuna where management is based on changes in absolute abundance from gene tagging, longline CPUE and close-kin mark recapture (Anon. 2020). The ongoing MSE for bigeye tuna in the EPO uses the models developed from the latest benchmark stock assessment (SAC-15-02) as operating models describing different hypothesis about the dynamics of the stock and fishery and a simple estimation model (age-structured production model with recruitment deviates) to derive management (SAC 15-07).

6. MANAGEMENT STRATEGY EVALUATION

The HCR adopted by Resolution C-16-02 and its amendment C-23-06, along with other harvest strategy elements currently in use at IATTC for managing tropical tunas, have not been comprehensively evaluated yet. The evaluation has been complicated due to several reasons, including 1) the current HCR in place is not fully specified, 2) the assessment method is too computationally intensive, and 3) some of the practical management actions have changed recently (e.g. inclusion of individual vessel thresholds) and are not currently possible to evaluate accurately (e.g. active FAD limits, individual vessel thresholds). MSE testing generally requires well specified strategies, simple assessment methods and management measures.

Initial simulation testing work of a simplified HCR was conducted in 2016 and 2018 and substantial progress has been made on developing operating models for bigeye tuna and other components of the ongoing MSE for bigeye tuna in the EPO (SAC 15-07). A proper MSE process requires a complete specification or alternative strategies to evaluate, for which the input and participation of managers and other stakeholders was sought during a series of IATTC sponsored and European Union funded MSE Workshops. Although there are no dedicated, formal communication channels on MSE (such as a Working Group) within the IATTC, SAC meetings and dedicated workshops provide opportunities for dialogue, communication, and training on MSE. There have been requests by stakeholders and SAC-14 recommendations for the Commission to consider establishing a dedicated dialogue Working Group, which could enhance or replace the MSE workshops.

Tropical tuna fisheries in the EPO are mixed fisheries (BET, YFT and SKJ), with management based on the species needing the strictest management as determined by single species stock assessments. Historically, the estimated status of BET has determined management for tropical tunas (although yellowfin tuna in some years) and was therefore selected as the initial focus of MSE work. Although the ultimate goal is to evaluate harvest strategies in a multispecies context, experience from RFMOs and other organizations show that MSE processes are multi-year undertakings, even for single species. Given the limited and time-constrained funds available for MSE of EPO tropical tunas to date, it was decided to start with BET on the technical work, adding the other species (tentatively SKJ first and then YFT) as their current assessment models are improved and operating models covering the main hypotheses about stock and fishery dynamics can be implemented. The stakeholder engagement has focused on dialogue on the three species, and the technical work conducted for BET is expected to streamline the MSE work on YFT and SKJ as their modelling improves. In addition to being multispecies fisheries, they are also multi-gear (purse-seine, longline) and multiple fishing modes (FAD, Dolphin, NOA) and thus present several challenges: 1) they are more difficult to simulate and evaluate, 2) different objectives may exist for different fisheries, 3) and whether management should be based on the species needing the strictest management, the 3 species individually, or a group of species? There are very few truly multispecies MSEs in the world, oftentimes they focus on gear interactions (Punt et al., 2016), which will probably be the approach taken by staff. Components of the harvest strategies for tropical tunas in the EPO, and their evaluation, will continue to be discussed, refined and planed as part of the next 5-year scientific strategic plan.

7. EXAMPLES OF TUNA HARVEST STRATEGIES

All tuna RFMOs are actively developing harvest strategies for stocks under their jurisdictions, some examples are included in this section to provide context for some of the decisions that need to be made while specifying elements of the harvest strategy for tropical tunas in the EPO. The status of tuna harvest strategies around the world is available at https://harveststrategies.org, at each RFMO and in yearly reports by ISSF.

7.1 NORTH PACIFIC ALBACORE

IATTC and WCPFC adopted a full harvest strategy for North Pacific albacore in 2023 (IATTC Resolution C-23-02), which will be applied for the first time in 2024 based on the latest stock assessment performed in 2023. It is a model-based strategy that uses regular full stock assessment estimates every 3 years to derive fishing intensity (the translation between fishing intensity and actual management action still needs to be specified), with a provision to review of the performance by 2030 and 2033. The main harvest strategy elements are outlined below:

Type of strategy: Model-based (full stock assessment)

Management cycle: 3 years

Strategy inputs: Regular stock assessment estimates

Management measures: conversion between fishing intensity and actual management action still needs to be specified (see SAC-15 INF-T)

Operating models:

Four operating models (or reference scenarios) were used to consider uncertainties in natural mortality, steepness, and growth:

1) Scenario 1 with high plausibility and moderately high stock productivity
2) Scenario 3 with medium plausibility and the highest stock productivity
3) Scenario 4 with medium plausibility and moderately low stock productivity
4) Scenario 6 with low plausibility and the lowest stock productivity.

Management Objectives:

i. Maintain Spawning Stock Biomass (SSB) above the Limit Reference Point, with a probability of at least 80% over the next 10 years.

ii. Maintain depletion of total biomass around historical (2006-2015) average depletion over the next 10 years.

iii. Maintain fishing intensity (F) at or below the target reference point with a probability of at least 50% over the next 10 years.

iv. To the extent practicable, management changes (e.g., catch and/or effort) should be relatively gradual between years.

Performance Indicators:

a) Probability that SSB in any given year of the MSE forward simulation is above the LRP
b) Probability that depletion in any given year of the MSE forward simulation is above minimum historical (2006-2015) depletion.

c) Probability that catch in any given year of the MSE forward simulation is above average historical (1981-2010) catch.

d) Probability that catch averaged over years 7-13 of the simulation is above average historical (1981-2010) catch.

e) Probability that catch averaged over years 20-30 of the simulation is above average historical (1981-2010) catch.

f) Probability that a decrease in TAC (or catch for mixed control) is <30% between consecutive assessment periods (once every 3 years), excluding years where TAC=0.

g) Probability of SSB > SSBthreshold

Limit reference point: LRP =14%$SSB_{current,F=0}$, which is 14% of the dynamic SSB_0.

Threshold reference point: $SSB_{threshold}$ = 30%$SSB_{current,F=0}$, which is 30% of the dynamic unfished spawning stock biomass.

Target reference point: TRP = F45%, which is the fishing intensity (*F*) level that results in the stock producing 45% of spawning potential ratio (SPR).

Harvest control rule (Figure 1):

If $SSB_{current}/SSB_{current,F=0}$ is above or equal to $SSB_{threshold}$ with a probability of at least 50%, fishing intensity shall be maintained at or below the TRP on average over 10 years.

If $SSB_{current}/SSB_{current,F=0}$ is below $SSB_{threshold}$ with a probability greater than 50%, and is above the LRP with a probability of at least 50%, fishing intensity shall be reduced to a level in accordance with the formula:

$$F = (TRP - F_{min}/SSB_{threshold} - LRP) * (SSB_{current}/SSB_{current,F=0} - LRP) + F_{min}$$

If $SSB_{current}/SSB_{current,F=0}$ is at or below the LRP with a probability of greater than 50%, the IATTC shall, in collaboration with the ISC and in coordination with the WCPFC, adopt rebuilding measures that will rebuild SSB to levels of at least the $SSB_{threshold}$ with a probability of at least 65% within 10 years of $SSB_{current}/SSB_{current,F=0}$ having been identified to be at or below the LRP with a probability greater than 50%. In the absence of such rebuilding measures, fishing intensity shall be set at F_{min}.

If $SSB_{current}/SSB_{current,F=0}$ is above the LRP and below $SSB_{threshold}$ the maximum increase or decrease in catch or effort between the three-year management periods shall be 20% relative to the catch and effort levels specified for the previous year.

Exceptional circumstances:

Exceptional circumstances have not been adopted yet, but criteria have been developed (SAC-15 INF-S) focusing on changes on stock and fleet dynamics (evidence from stock assessment estimates that the stock is in a state not previously simulated in the MSE, new evidence about the biology of the stock or fleet structure/or fishing operations have changed substantially); application (data collection required to produce the stock assessment is no longer available and/or appropriate to apply the adopted harvest strategy) and implementation (management action is substantially different from what is prescribed by the HCRs).

7.2 IOTC BIGEYE

The Indian Ocean Tuna Commission (IOTC) adopted a fully specified management procedure for bigeye tuna in 2022 (IOTC Resolution 22/03), exceptional circumstances are still to be specified. The management procedure is model based, using a simple estimation method (Pella Thomlison state space model) that uses catches and longline CPUE, applied every 3 years to derive catch quotas as the management action. The main harvest strategy elements are outlined below:

Type of strategy: Model-based (simple biomass dynamic model)

Management cycle: 3 years

Strategy inputs: catches and longline CPUE

Management measures: Catch quota

Operating models:

A reference set of 72 operating models capture uncertainty through combinations of different levels of the following:

1. Recruitment: the number of age 1 fish; reflects stock productivity over time (3 levels)
2. Natural mortality: the percent of individuals who die of natural causes at a given age (3 levels)
3. Tag recapture: different weightings on the reliability of the tagging data (3 levels)
4. Assumed longline catchability trend: whether or not catchability has increased in the longline fishery (2 levels)
5. Regional scaling of longline CPUE (2 levels)
6. Longline fishery selectivity (2 levels)
7. Effective Sample Size (ESS) which determines how informative the size composition data is (2 levels)

A robustness set of 5 operating models is used to test the candidate MPs against more extreme, but plausible, scenarios. Those include reduced information content of the longline CPUE, overcatch implementation error (either reported or not reported), 3% increase in catchability during projections and a recruitment reduction shock (55% over 8 quarters).

Management Objectives:

a) Maintain the stock biomass in the green zone of the Kobe plot (not overfished and not subject to overfishing) while maximizing average catch and reducing the variation in the total allowable catch (TAC) between management periods.

b) The bigeye tuna spawning stock has a 60% probability of achieving the target reference point of SB_{MSY} by 2034-2038;

c) The bigeye tuna spawning stock biomass avoids breaching the interim limit reference point of $50\%B_{MSY}$ with a high probability

Performance Indicators:

a) Average catches

b) Probability of initial catch decrease

c) Catch variability

d) Range of Biomass and Fishing mortality at the end of projection period

e) Probability B>BLIM over the projection period (in robustness test)

f) Probability F<FMSY over the projection period (in robustness test)

g) Recovery from a poor recruitment period (in robustness test)

Limit Reference Point (Interim): 50% B_{MSY} and 130% F_{MSY}

Target Reference Point (Interim): B_{MSY} and F_{MSY}

Harvest control rule (Figure 3):

A hockey-stick HCR is used to derive a harvest rate based on biomass depletion relative to carrying capacity. The control points are at 40% and 10% of carrying capacity, with the HCR multiplier linearly decreasing from 1 to almost zero between those control points.

Maximum quota changes are capped at +/- 15%.

$HCR_{mult} = 1 \; if \; B_y/K \geq 0.4$

$HCR_{mult} = (B_y/K - 0.1)/\; 0.3 \; if \; 0.1 < By/K < 0.4$

$HCR_{mult} = 0.0001 \; if \; B_y/K \leq 0.1$

$TAC_{new} = B_y(1 - exp(-F_{mult} \times HCR_{mult} \times F_{MSY} \; ratio))$

Exceptional circumstances:

Exceptional circumstances have not been adopted yet, but the process for evaluating exceptional circumstances adopted by the IOTC SC is described in (Anon, 2021). If exceptional circumstances are triggered, the pre-existing TAC shall remain in place until a new TAC or other management action is agreed by the Commission.

7.3 WCPFC SKIPJACK

A harvest strategy for skipjack tuna was adopted by the Western and Central Pacific Fisheries Commission in 2022 (CMM 2022-01). The strategy is model-based, applied every 3 years to derive effort or catch measures. Main harvest strategy elements are described below:

Type of strategy: model-based

Management cycle: 3 years

Strategy inputs: stock assessment estimates of spawning potential depletion ratio for the latest estimation year ($SB_{latest}/SB_{F=0,\,t1\text{-}t2}$),

Management measures: Effort or catch measures

Operating models:

Based on the 2019 skipjack stock assessment resulting in a grid of 96 models, representing different configurations of Recruitment Variability, Observation Error, Catch and effort, Size composition (ESS), Tag recaptures, Model Error, Steepness, Mixing period, Growth, Movement, El Nino/La Nina, DD catchability, Implementation Error and Effort creep. Models are divided into a reference set (most plausible hypotheses, used to calculate performance metrics) and a robustness set (considered less likely but still plausible).

Management Objectives:

To ensure that:

a) the spawning potential depletion ratio of skipjack tuna is maintained on average at a level consistent with the target reference point;

b) the spawning potential depletion ratio of skipjack tuna is maintained above the limit reference point with a risk of the limit reference point being breached no greater than 20%

Performance Indicators:

a) Maintain SKJ, YFT, BET biomass at or above levels that provide fishery sustainability throughout their range.

b) Maximize economic yield from the fishery (average expected catch).

c) Maintain acceptable CPUE.

d) Catch stability.

e) Effort stability: effort variation relative to a reference period.

f) Proximity of $SB/SB_{F=0}$ to the average $SB/SB_{F=0}$ in 2018-21.

Target reference point: calculated using two biomass depletion levels:

(a) the equilibrium SSB of skipjack tuna average depletion level over the period 2018-2021 and

(b) long-term equilibrium SSB that would be reached based on agreed baseline fishing effort.

The TRP is the average of both depletion levels, calculated as medians from the stock assessment grid.

Limit reference point: 20 percent of the estimated recent (last 10 years) average spawning potential in the absence of fishing.

Harvest Control Rule (Figure 3):

The HCR is a scalar (multiplier) that adjusts future catch or effort relative to a baseline historical value that varies by fishery. Scalars apply to effort for purse seine fisheries, and to catch for all other fisheries. The HCR is defined as follows:

If $SB/SB_{F=0}>0.8$, output multiplier = 1.4 (alt. 1.2)

If $0.47<SB/SB_{F=0}<0.8$, reduce effort linearly as specified in HCR

If $0.37<SB/SB_{F=0}<0.47$, output multiplier = 1

If $0.2<SB/SB_{F=0}<0.37$, reduce effort nonlinearly as specified in HCR

If $SB/SB_{F=0}<0.2$ (the limit), output multiplier 0.2

Maximum effort change: +/-10% for any 3-year management cycle, relative to catch and effort specified by the HCR for the previous 3-year period

Exceptional circumstances:

Exceptional circumstances for WCPFC skipjack tuna are described in Annex IV of CMM 2022-01. They include routine annual evaluation of potential exceptional circumstances based on information presented to and reviewed by SC; and detailed evaluation of potential exceptional circumstances every 3 years coincident with the stock assessment. Listed events of what might constitute exceptional circumstances include:

1) Persistent low recruitment outside the range for which the MP was tested;

2) Substantial improvements in knowledge, or new knowledge, concerning the dynamics of the population which would have an appreciable effect on the operating models used to test the MP;

3) Non-availability of important input data resulting in an inability to run the MP;

4) Stock assessment biomass estimates that are substantially outside the range of simulated stock trajectories considered in the MP evaluations, calculated under the reference set of operating models;

5) significant increases in the contribution of fisheries not affected by the MP impacting stock depletion;

6) Failure of reported catches and effort to be within an acceptable range around the levels indicated by the MP; and

8. SUMMARY AND CONCLUSIONS

The IATTC has adopted elements of a harvest strategy for tropical tunas such as interim 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, probability of being above target reference points) and other elements added (e.g. type, duration and derivation of management actions) to constitute a complete strategy and help in its evaluation. The main working harvest strategy elements utilized during the ongoing bigeye tuna MSE (SAC-15-07) are outlined below:

Type of strategy (proposed): Model-based (simple biomass dynamic model, age structured production model with recruitment deviates)

Management cycle (proposed): 1 or 3 years

Strategy inputs (proposed): total catch, Japanese longline index of relative abundance (CPUE)

Reference points: interim as defined in Resolution C-16-02 and its amendment C-23-06, also note staff proposed new proxy reference points for tropical tuna (SAC-15-05)

Operating models:

Based on the model grid from the 2024 bigeye tuna stock assessment (SAC-15-02, SAC-15-07). Main structural uncertainties of the 2024 bigeye tuna model ensemble that will be carried into the MSE as alternative states of nature includes 36 model configurations with different assumptions on individual growth, selectivity for fisheries (asymptotic or all dome), steepness of the Beverton-Holt stock recruitment relationship (h values: 1.0, 0.9, 0.8), natural mortality () and three rates of annual increase in longline catchability (0%, 1%, 2%).

Management Objectives:

General objectives are defined in IATTC's Antigua Convention's Article IV (c) stating *"to ensure the long-term conservation and sustainable use of the fish and to maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield"*.

Additional proposed objectives resulting from stakeholder input and IATTC MSE workshops are listed in Table 1.

Performance Indicators: Not defined yet, alternatives discussed during recent IATTC MSE workshops are listed in Table 1.

Harvest control rules:

Alternative HCRs discussed during the 3rd IATTC Workshop on tropical tuna MSE as candidates for evaluation during the bigeye tuna MSE are shown in Figure 4.

Exceptional circumstances: Not defined yet

9. REFERENCES

Anon. 2020. Specifications of the CCSBT Management Procedure. Attachment 8, Report of the Twenty Fifth Meeting of the Scientific Committee. 7 September 2020.

Anon. 2021. Report of the 24th Session of the IOTC Scientific Committee. IOTC–2021–SC24–R[E], Appendix 6A.

Hillary, R., Williams, A., Preece, A; Jumppanen, P. 2021. Indian Ocean Bigeye Tuna Management Procedure Evaluation Update. Hobart: CSIRO; 2021. csiro:EP2022-1479.

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

TABLE 1. Objectives, quantities and performance indicators summarized during the 3rd IATTC MSE workshop (from SAC-15-07).

OBJECTIVE	Quantity	Performance Indicators
Safety *Maintain stock above limit reference points*	*Equilibrium virgin spawning biomass* S_0 • *< 10% probability SB below 7.7% of* S_0 • *< 5% probability SB below 7.7% of* S_0 < 10% P SB < Smsy Flim (< 5% *P* F > Fmsy)	Ratio of S_{yr} over S_0 Probability calculated over projected 30 years (All years, any year by replicates)
Status Maintain stock in green quadrant of Kobe plot	SB≧ dynamic SB_{MSY} and $F<F_{MSY}$ • *60% probability* • *75% probability*	% of simulated runs falling in Kobe's green quadrant Probability calculated over projected 30 years
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) • *1994-2019 (since FAD expansion)* • *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)

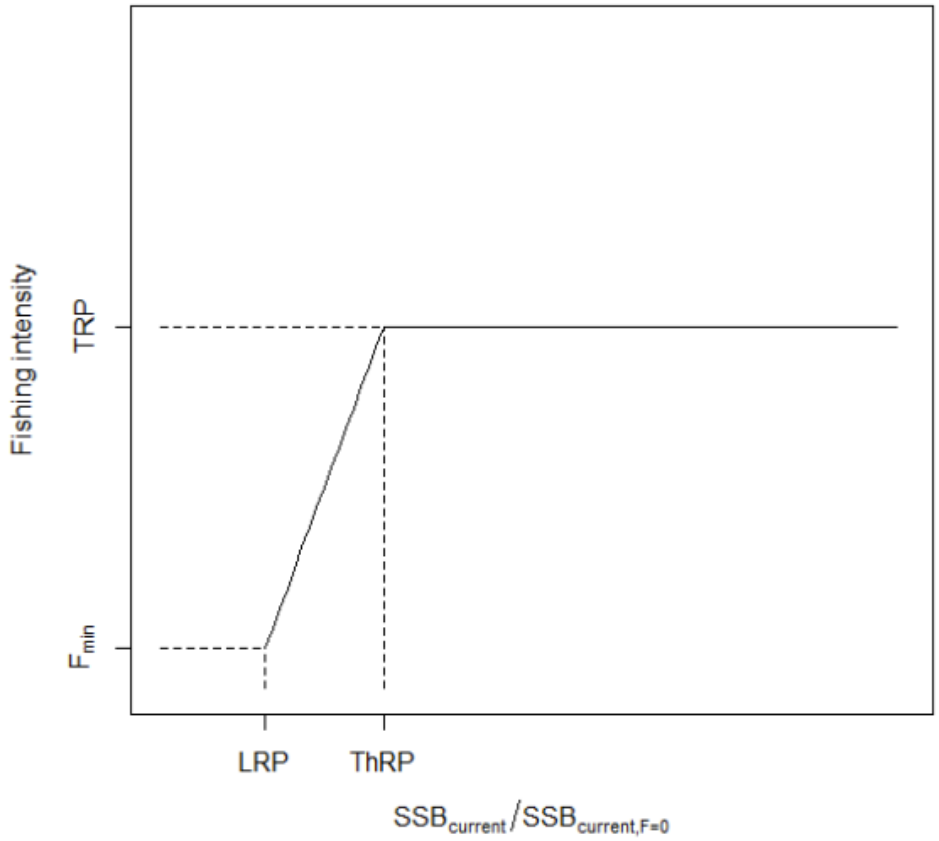

FIGURE 1. Harvest control rule adopted for the IATTC/WCPFC North Pacific Albacore harvest strategy (from IATTC Resolution C-23-02).

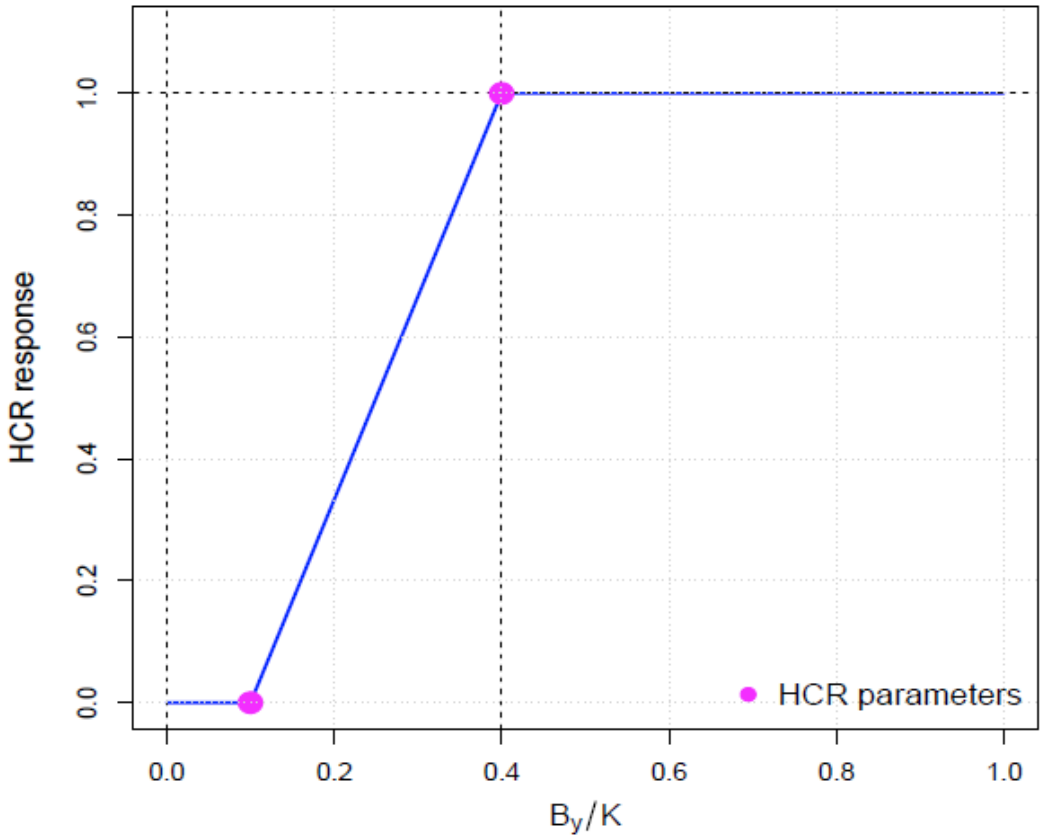

FIGURE 2. Harvest control rule adopted for IOTC bigeye tuna management procedure.

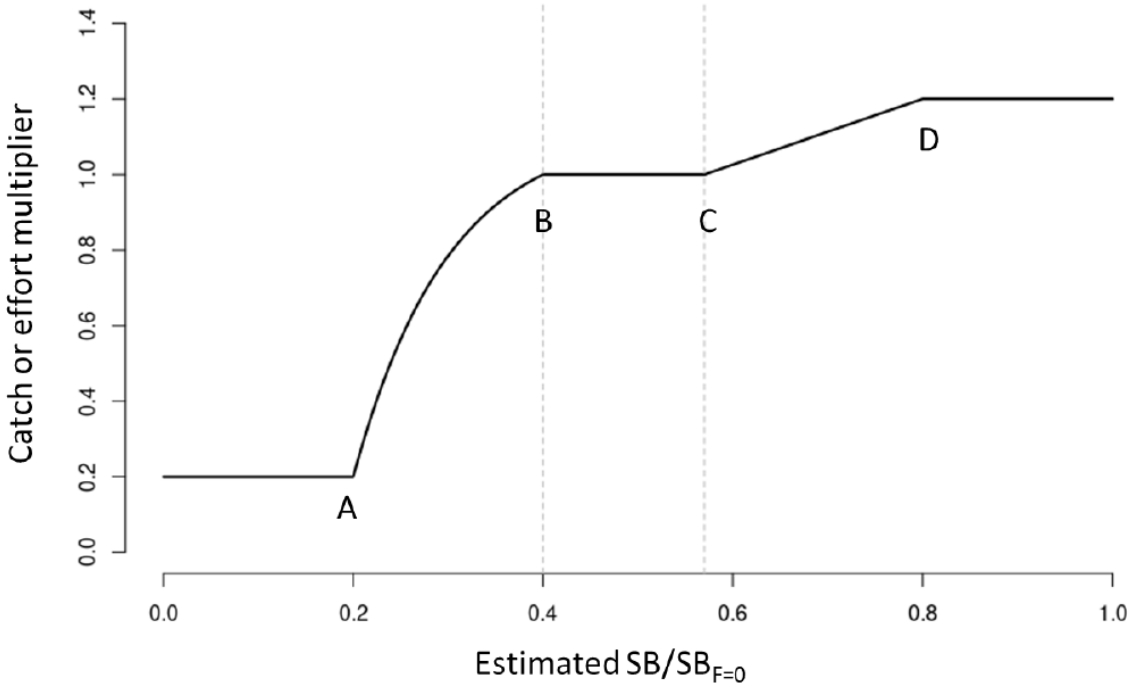

FIGURE 3. Harvest control rule adopted for the WCPFC skipjack tuna harvest strategy (from CMM 2022-01).

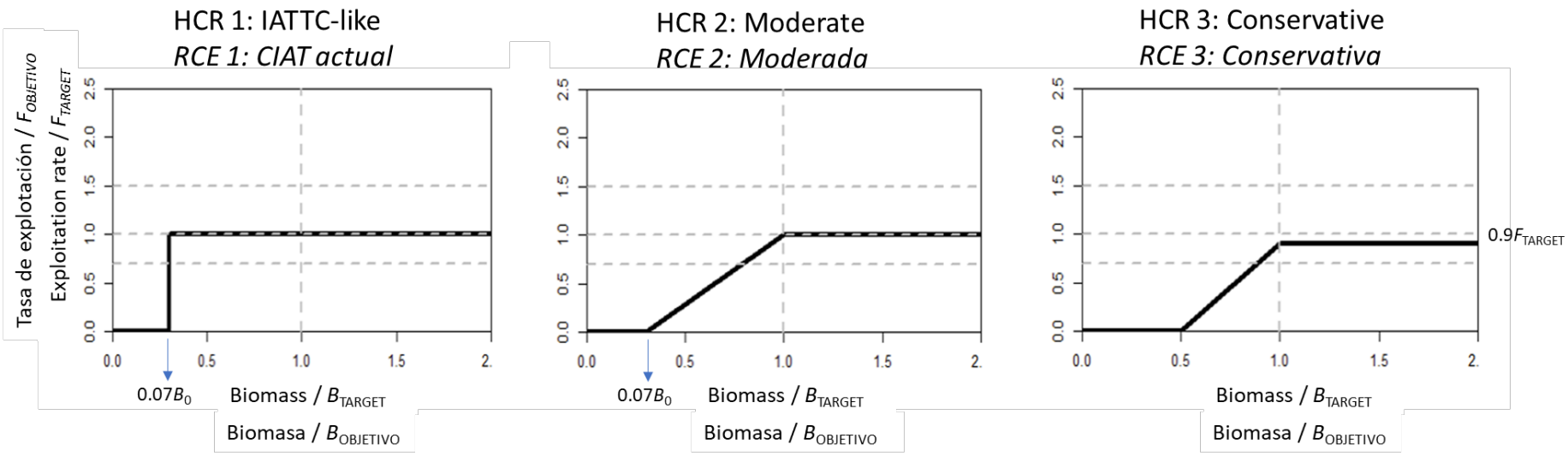

FIGURE 4. Alternative Harvest Control Rules (HCR) discussed during the 3rd IATTC Workshop on tropical tuna MSE as candidates for evaluation during the bigeye tuna MSE. B_{TARGET} and F_{TARGET} are either MSY-based quantities or $B_{30\%}$ and $F_{30\%}$. (from SAC-15-07).