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SUMMARY OF TUNA HARVEST STRATEGIES ADOPTED AND IN DEVELOPMENT ACROSS TUNA RFMOS

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CONTENTS

1. INTRODUCTION

Management strategies (often referred as harvest strategies or 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, to specify the components, 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, CCSBT the furthest along with a successful MSE development, testing and implementation of a management procedure already in place and IATTC at the earliest stage in the process.

This document describes harvest strategy elements already adopted or in development for tuna stocks across tuna RFMOs, including at the IATTC. It also outlines elements in need of refinement or in need of adoption. It is not intended to be an exhaustive review, and some items still require completing, but instead a living document that can be updated as development of harvest strategies, their evaluation and adoption continues at IATTC and the other t-RFMOs.

2. 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.

2.1 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 the performance in 2030 and 2033. The main harvest strategy elements are outlined below:

Type of strategy: Model-based. Uses the latest full stock assessment available, an integrated age-structured model fit to catch at length and other data.

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 using as the basis the integrated assessment model:

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 the historical (2006-2015) average depletion level 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 $SSB > SSB_{threshold}$

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:

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

Where (F_{min}) equal to F87%, which is the fishing intensity (F) level that results in the stock producing 87% of SPR.

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).

2.2 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 2):
A hockey-stick HCR is used to derive a harvest rate based on biomass depletion relative to carrying capacity (where carrying capacity, K, is a parameter in the Pella-Tomlinson model and is neither spawning biomass nor vulnerable biomass, but is consistent with the measure of biomass). 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%.
$HCR_{mult} = 1\ if\ B_y/K \geq 0.4$
$HCR_{mult} = (B_y/K - 0.1)/\ 0.3\ if\ 0.1 < By/K < 0.4$
$HCR_{mult} = 0.0001\ if\ B_y/K \leq 0.1$
$TAC_{new} = B_y(1 - exp(-F_{mult} \times HCR_{mult} \times F_{MSY}\ ratio))$

Where F_{mult} is a tuning parameter and F_{MSY} ratio is the ratio of fishing mortality to the value estimated to produce the maximum sustabiable yield (F/F_{MSY}).

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.

2.3 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 ($SB_{\text{latest}}/SB_{F=0,\ t1\text{-}t2}$), where t1=*y*-10 to t2=*y*-1 where *y* is the year under consideration, that is the last 10 years based on the most recent skipjack stock assessment.

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 sample size (ESS), Tag recaptures, Model Error, Steepness, Mixing period, Growth, Movement, El Nino/La Nina, density dependent 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 ($SB_{2018-2021}/SB_{F=0}$) 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 (Figure 3)
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 (Figure 3)
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

2.4 WCPFC BIGEYE TUNA

Type of strategy: There is no complete harvest strategy adopted yet, however some components have already been agreed. The developing strategy includes a mixed fishey modelling framework that develops model-based harvest strategies for bigeye, but is set up to achieve objectives across multiple species, including yellowfin, skipjack, and South Pacific albacore.

Management cycle:
Management plan is amended annualy

Management measures:
Management measures for bigeye during 2024-2027 are described in CMM 2023-01, it includes serveral measures such as: 1) Seasonal closure of fishing on FADs; 2) use of non-entangling, biodegradable and retrievavble FADs; 3) individual vessel limits of active FADs; 3) limits in the number of vessel days; 4) full retention; 5) 100% observer coverage on purse seine vessels; 6) limits on the number of purse seine and longline vessels; 7) Flag-specific catch limits for non-SIDS fleets; 8) bigeye catch limits caught by longliners may be increased if linked to a proportional increase of observer coverage.

Management Objectives: Although they are not defined yet, there was an agreed specifiec interim maximum acceptable risk of 20% for breaching the LRP, agreed in 2016.

Performance Indicators:
Candidate performance indicators have multispecies considerations such as (from the Skipjack harvest strategy): Maintain SKJ, YFT, BET biomass at or above levels that provide fishery sustainability throughout their range.

Limit reference point:
20% of the average spawning biomass expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions (20%SSBcurrent, F=0). The median value of SSBrecent/SSBF=0 is 0.35, which is above this limit.

Target reference point:
Althought not defined yet in the long term, the spawning biomass depletion ratio (SB/SBF=0) is to be maintained at or above the average SB/SBF=0 for 2012-2015.

Harvest control rule:
Not yet defined

Exceptional circumstances:
Not specified yet

2.5 WCPFC YELLOWFIN TUNA

Type of strategy: The is no complete strategy adopted yet, however CMM 2023-01 contains elements of a harvest strategy. Ongoing work under a mixed fishery framework.

Management cycle:

Strategy inputs:

Management measures:
Combination of measures incuding seasonal closures between 20°N and 20°S for purse-seine vessels fishing on FADS, limits on the number of drifting FADs per vessel, limits on vessel days, full retention, 100% observer coverage.

Operating models:

Management Objectives:
Not defined yet. Interim maximum acceptable risk of 20% of breaching the LRP agreed in 2016.

Performance Indicators:

Limit reference point: 20% of the spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($20\%_{SSBcurrent,\ F=0}$)

Target reference point: Pending agreement on a TRP, the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ estimated for 2012-2015, which is a value of 0.44 calculated across the unweighted 2023 model grid.

Harvest control rule: Not defined yet.

Exceptional circumstances:
Not defined yet

2.6 PACIFIC BLUEFIN TUNA

Type of strategy: Model-based strategy, in development

Management cycle:

Strategy inputs:

Management measures: TAC. Relative *F* is used to develop catch measures to obtain desired impact by fleet.

Operating models: Model grid based on alternative levels of steepness, natural mortality, and growth. Model diagnostics used to define grid.

Management Objectives: Not agreed yet. Interim objectives from WCPFC:

1. Support thriving Pacific bluefin tuna fisheries across the Pacific Ocean while recognizing that the management objectives of the WCPFC are to maintain or restore the stock at levels capable of producing maximum sustainable yield
2. Maintain an equitable balance of fishing privileges among countries
3. Seek cooperation with IATTC to find an equitable balance between the fisheries in the western and central Pacific Ocean (WCPO) and those in the eastern Pacific Ocean (EPO).

Performance Indicators:

Rebuilding Targets: Initial, Historical median biomass (equivalent to 6.4%SSB0) by 2024; Second, 20%SSBF=0 by 2034

Limit reference point: Candidates: 5%SSBF=0, 7.7%SSBF=0, 15%SSBF=0, 20%SSBF=0

Threshold reference point: Candidates: 15%SSBF=0, 20%SSBF=0, 25%SSBF=0

Target reference point: 10%FSPR, 15%FSPR, 20%FSPR, 30%FSPR, 40%FSPR

Harvest control rule: Linearly changing HCRs are being explored in the initial MSE work, with a view to develop a comprehensive harvest strategy.

Exceptional circumstances:

2.7 SOUTH PACIFIC ALBACORE

Type of strategy: model-based and empirical. Also being incorporated in the mixed fishery MSE framework for the Western and Central Pacific in which the harvest strategies for bigeye, skipjack, yellowfin, and South Pacific albacore will overlap.

Management cycle:

Strategy inputs: CPUE data

Management measures:

Operating models:

Management Objectives (Interim):
Achieve an 8% increase in catch per unit of effort (CPUE) for the southern longline fishery as compared to 2013 levels

Performance Indicators (Candidate):

1. Maintain biomass at or above levels that provide fishery sustainability throughout their range

2. Maximise economic yield from the fishery (average expected catch)
3. Maintain acceptable CPUE
4. Catch stability

Limit reference point (Interim): 20%SBF=0 and FX%SPR, with X to be determined

Target reference point (Interim): 56% SBF=0

Harvest control rule: model-based and empirical HCRs considered

Exceptional circumstances:
Not defined yet

2.8 IOTC YELLOWFIN TUNA

Type of strategy: model-based

Management cycle: 3-year cycle

Strategy inputs: Stock assessment estimates

Management measures:

Operating models:

Management Objectives:
Objectives used in the MSE
Pr(B(2029)>=B(MSY)) = 0.5 (SB in 2029 exceeds SBMSY in exactly 50% of the simulations)
Pr(B(2034)>=B(MSY)) = 0.6 (SB in 2034 exceeds SBMSY in exactly 50% of the simulations)

Performance Indicators:

Limit reference point: Interim 40% B_{MSY} and 140% F_{MSY}

Target reference point: Interim B_{MSY} and F_{MSY}

Harvest control rule: model-based HCRs with these candidate constraints:
1. Total Allowable Catch (TAC) to be set every 3 years (and held constant between settings)
2. A maximum of 15% change to the TAC (increase or decrease) relative to the previous TAC

Exceptional circumstances:
Not defined yet

2.9 IOTC ALBACORE

Type of strategy: Model-based and empirical

Management cycle: 3-years

Strategy inputs: CPUE-data

Management measures: TAC (Catch quota)

Operating models:
The Operating Models were developed based on the integrated age-structured stock assessment.

Management Objectives:

1. Pr(mean(SB(2034:2039)>=SB(MSY)) = 0.5. Average SB over the period 2034-2039 exceeds SB_{MSY} in exactly 50% of the simulations)
2. Pr(Kobe green zone 2034:2039) = (0.5, 0.6, 0.7). The stock status is in the Kobe green quadrant over the period 2034:2039 exactly (50%, 60%, 70%) of the time (averaged over all simulations)

Performance Indicators:
Mean catch, mean F/F_{MSY}, F/F_{target}, Catch/MSY, SB/SB_0, min(SB/SB_0), % internannual change in catch, *P*(Kobe green quadrant), *P*(Kobe red quadrant), *P*(shutdown), *P*(SB > 20%SB_0), *P*(SB > SB_{limit}).

Limit reference point (Interim): 40% BMSY and 140% FMSY

Target reference point (Interim): BMSY and FMSY

Harvest control rule:
1. Total Allowable Catch (TAC) to be set every 3 years (and held constant between settings)
2. A maximum of 15% change to the TAC (increase or decrease) relative to the previous TAC

2.10 IOTC SKIPJACK TUNA

Type of strategy:
Currently Model-based. An empirical, data-based strategy is currently being simulation tested

Management cycle: 3-year cycle

Strategy inputs:
Stock assessment estimates of current spawning stock biomass (B_{curr}); unfished stock biomass (B_0); equilibrium exploitation rate (E_{targ}) associated with sustaining the stock at Btarg

Management measures:
Catch quota

Operating models:

Management Objectives:
1. Maintain stock at levels that can produce MSY, as qualified by relevant environmental and economic factors
2. Use HCR to maintain stock at or above the target and well above the limit

Performance Indicators:

Safety reference point: 10%B_0

Limit reference point: 20%B_0

Target reference point: 40%B_0

Harvest control rule:
Current HCR to be expanded to a fully specified harvest strategy in 2024. HCR reduces catch linearly from the threshold level (0.4B_0) to the safety level (0.1B_0); zero catch below safety level, except for subsistence fisheries. Changes have a maximum quota change of +/- 30% and a maximum catch limit of 900,000 t.

Exceptional circumstances:

2.11 SOUTHERN BLUEFIN TUNA

Type of strategy: Empirical. Fully-specified 'Cape Town Procedure' adopted in 2019 was tested through comprehensive MSE process.

Management cycle: 3 years

Strategy inputs: CPUE, genetics

Management measures: Quota

Operating models: Consisting of a reference set and a robustnes set of models. Main uncertainties are incorporated in more than 100 OMs including the the cross-combination of four values of steepness (h), three values of natural mortality at age 0 (M0), three values of mortality at age 10 (M10), a single value of Omega (Ω) (implying a linear relationship between CPUE and LL1 exploitable biomass), a single age range used to standardise LL1 selectivity over time, a single CPUE series (GAM), and three values of Psi (ψ) (the power parameter for relative reproductive contribution by age).

Management Objectives:
"Ensure, through appropriate management, the conservation and optimum utilization of southern bluefin tuna", operationalized as:
30% SSB0 by 2035, with a 50% chance of success

Performance Indicators:

Limit reference point: 24% SSB0

Target reference point: 30% SSB0 by 2035, with a 50% chance of success

Harvest control rule:

Hybrid rule that increases or decreases quota using model-based log-linear trend in adult biomass inferred by an age-structured model using genetic data and an empirical-based-staged response to CPUE.

Exceptional circumstances:

2.12 NORTH ATLANTIC ALBACORE

Type of strategy: Model-based. Adopted in 2021, ICCAT successfully converted the HCR into a full harvest strategy through the addition of an exceptional circumstances protocol and the specification of the data collection and assessment methods needed to apply the HCR.

Management cycle: 3-years

Strategy inputs:

Management measures: Quota

Operating models:

Management Objectives:

1. Maintain stock in green quadrant of Kobe plot with at least 60% probability while maximizing long-term yield
2. Rebuild to or above SSB_{MSY} with at least 60% probability within as short a time as possible, while maximizing average catch and minimizing TAC changes

Performance Indicators:

Limit reference point: 40%B_{MSY}

Threshold reference point: B_{MSY}

Target reference point: 80%F_{MSY}

Harvest control rule:

1. If B> $B_{THRESHOLD}$ (B_{MSY}), fish at FTARGET (80% F_{MSY})
2. If B_{LIM} <B<$B_{THRESHOLD}$, reduce F linearly as specified to 10% F_{MSY}
3. If B< B_{LIM}, suspend fishery and initiate scientific monitoring at F_{MIN} (10% F_{MSY})

Exceptional circumstances:
Adopted based on three general principles:

1. When there is evidence that the stock is in a state not previously considered to be plausible in the context of the management strategy evaluation (MSE);
2. When there is evidence that the data required to apply the management procedure (MP) are not available or are no longer appropriate; and/or,
3. When there is evidence that total catch is above the TAC set using the MP.

2.13 WESTERN ATLANTIC SKIPJACK TUNA

Type of strategy:

Management cycle:

Strategy inputs:

Management measures:

Operating models:

Management Objectives:
Drafted at the conceptual stage:
1. Greater than [___]% probability of occurring in the green quadrant of the Kobe matrix
2. Less than [___]% probability of the stock falling below BLIM
3. Maximize overall catch levels
4. Any increase or decrease in TAC between management periods should be less than [___]%.

Performance Indicators:

Limit reference point: 40% dynamic SSBMSY

Target reference point: Dynamic SSB_{MSY}

Harvest control rule:
Testing a variety of harvest control rules, including constant catch and hockey stick harvest control rules (i.e., that adjust the total allowable catch up and down as the population size increases and decreases, respectively).

Exceptional circumstances:

2.14 WESTERN AND EASTERN ATLANTIC BLUEFIN TUNA

Type of strategy: Empirical

Management cycle: 3-years

Strategy inputs: Inputs are 10 fishery-dependent and fishery-independent indices of abundance covering the western and eastern Atlantic and Mediterranean Sea.

Management measures: Catch quota

Operating models:

Management Objectives:
1. Greater than 60% probability of occurring in the green quadrant of the Kobe matrix
2. Less than 15% probability of the stock falling below B_{LIM}
3. Maximize overall catch levels

4. Any increase or decrease in TAC between management periods should be less than +20% and -35% respectively

Performance Indicators:

Limit reference point: 40% dynamic SSBMSY

Target reference point: Dynamic SSB_{MSY}

Harvest control rule:
Indices are aggregated to produce master abundance indices for West and East and smoothed over years to reduce observation error and variability effects. Quotas are then set based on the concept of taking a fixed proportion of the abundance present, using relative harvest rates compared to a reference year (2017), as indicated by these aggregated and smoothed indices. Maximum quota change: +20%/-35%.

Exceptional circumstances:

2.15 EPO BIGEYE TUNA

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)

Limit Reference point: interim as defined in Resolution C-16-02 and its amendment C-23-06. 7.7% equilibrium virgin spawning biomass under a conservative steepness of *h*: 0.75, fishing mortality associated with that level of B_0.

Target Reference point: interim as defined in Resolution C-16-02 and its amendment C-23-06. Dynamic reference points based on B_{MSY} and F_{MSY}. Note staff proposed new proxy reference points for tropical tuna, around 30%B_0 (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 (Natural mortality *M* values for adult male 0.1, 0.12, 0.125, 0.13) 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

3. MULTI STOCK MSE

In addition to the tuna single stock MSE adopted or in development, there are several multi stock MSEs in development, including multi-stock tropical tunas in ICCAT (expected for 2026 or later) and a yellowfin-bigeye MSE in development at WCPFC.

4. SUMMARY AND CONCLUSIONS

Conducting MSE and implementing the resulting harvest strategies requires the specification and testing of several components (objectives, performance measures, operating models, estimation models, harvest control rules, etc.). These components can have a variety of specifications. All the tRFMOs have been developing harvest strategies and conducting MSE, but are at different stages in their implementation. There are differences among tRFMOs in the specification of the different components, but also some commonalities. The commonalities may provide guidance to tRFMOs that are at the early stages of MSE development like the IATTC.

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.

There are a range of management actions for the different stocks, even within a tRFMO. In some cases, the actions are simple (e.g., total allowable catch or effort by fleet, seasonal closures) and can easily be tested using MSE. In other cases, the management actions are complex (spatial closures, limits on active FADs, individual vessel thresholds) and difficult, if not impossible, to test using MSE. To facilitate the application of MSE, the management actions could be simplified. Otherwise, only fishing mortality strategies can be tested and the relationship between the management action(s) and fishing mortality needs to be estimated or assumed. Tropical tunas in the EPO are currently managed using temporal closures for purse seine vessels and catch limits for longline vessels. Other measures such as capacity limits, full retention, active FAD limits, spatial closures and BET Individual Vessel Thresholds (IVT) are also in place for some fleet components. A review of alternative management actions and analyses carried out over the past several years by the IATTC staff with respect to the purse seine fishery for tropical tunas in the EPO was conducted by Maunder et al (2021).

The choice of estimation model used in the MP restricts how many simulations can be applied in the MSE. For example, the north Pacific Albacore MSE uses the full stock assessment (integrated age-structured catch-at-length analysis) and therefore only has four operating models. Furthermore, as the full stock assessment evolves over time, it is not clear at which point it may diverge enough to potentially not reflect the robustness of the strategy that was evaluated under a previous version of the full assessment.
In contrast, the IOTC bigeye MSE uses a simple surplus production model and has 72 operating models, this simpler assessment is not expected to change over time as it typically happens in more complex integrated assessments. However, with enough resources, many operating models can be applied to a more complex stock assessment model as in the WCPFC skipjack MSE. Although, in the latter case, more human resources are needed to set up the simulations and interpret the results including determining if the operating models are properly converged and reasonable given diagnostics. Therefore, there is a tradeoff between the assessment used, the uncertainty represented, the human resources available, and the computational resources available.

Some major differences include the complexity, specificity and constancy over time of the stock assessment model, the number and type of uncertainty represented by the operating models, the complexity of the HCR, the target (or threshold) and limit reference points, among others.

Here we list some commonalities in components of MSE among tRFMOs, which can be a guide, not a prescription, to the development of MSE at the IATTC.

Type of strategy: Simplified assessment model (e.g. age-structured production model)

Management cycle: 3 years

Strategy inputs: catch and CPUE

Management measures: Catch or effort limits

Operating models: Ensemble based on current stock assessment

Management Objectives:

- Greater than [___]% probability of occurring in the green quadrant of the Kobe matrix
- Less than [___]% probability of the stock falling below BLIM
- Maximize overall catch levels
- Any increase or decrease in TAC between management periods should be less than [___]%.

Performance Indicators:

- Probability of occurring in the green quadrant of the Kobe matrix
- Probability of the stock falling below BLIM
- Average biomass level
- Average catch
- Catch variability i.e. probability of increase or decrease in being above [___]%.

Limit reference point: Varies, some dynamic, some equilibrium B_0

Target reference point: Varies, some dynamic, some equilibrium on varying fractions of MSY quantities (*F* and *B*), or biomass and *F* proxies. In oher instances historical ranges of years are considered.

Harvest control rule:
If SSB/SSBF=0 > SSBthreshold, F=Ftarget
If SSBlimit < SSB/SSBF=0 < SSBthreshold, F=linear decrease to X%Ftarget at SSBlimit
If SSB/SSBF=0 < SSBlimit, initiate rebuilding plan

Exceptional circumstances:

- When there is evidence that the stock is in a state not previously considered to be plausible in the context of the management strategy evaluation (MSE);
- When there is new evidence about the biology of the stock that will likely impact the MSE results or fleet structure/or fishing operations have changed substantially;
- When there is evidence that the data required to apply the management procedure (MP) are not available or are no longer appropriate; and/or,
- When there is evidence that implementation of the HCR (i.e. converting the specified *F* into actual management action e.g. effort or catch limits) is different than intended or evaluated.

5. REFERENCES

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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)

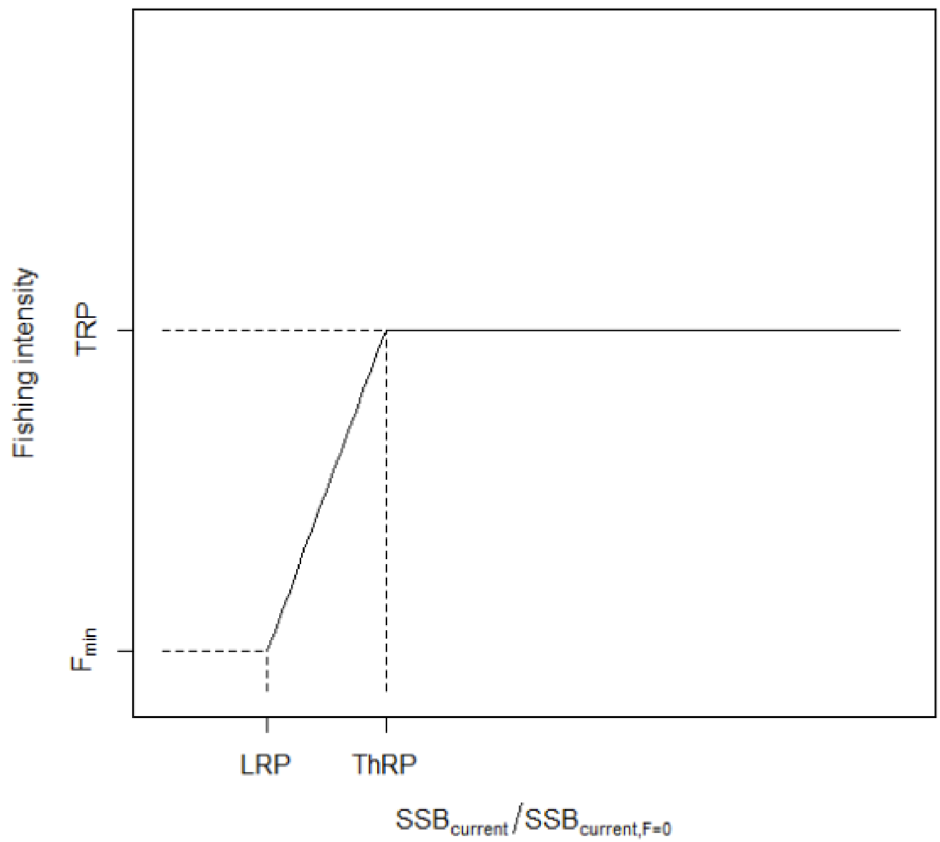

FIGURE 1. Harvest control rule adopted for the IATTC/WCPFC North Pacific Albacore harvest strategy (from IATTC Resolution C-23-02).

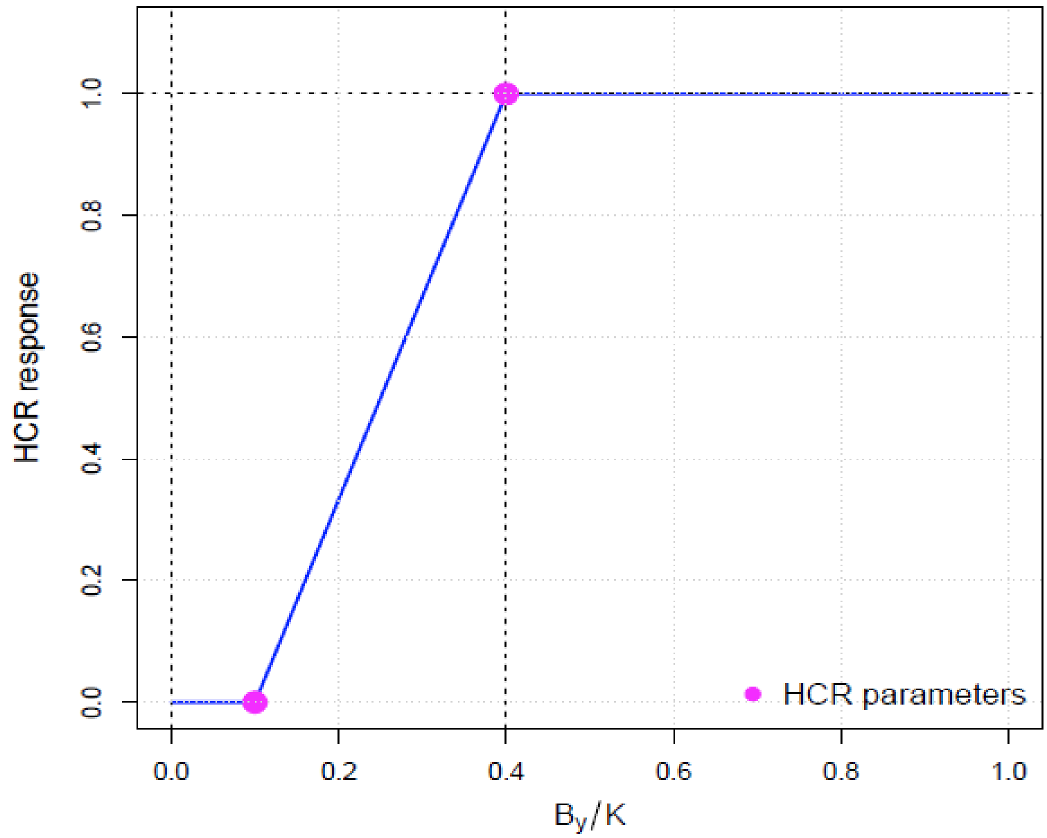

FIGURE 2. Harvest control rule adopted for IOTC bigeye tuna management procedure.

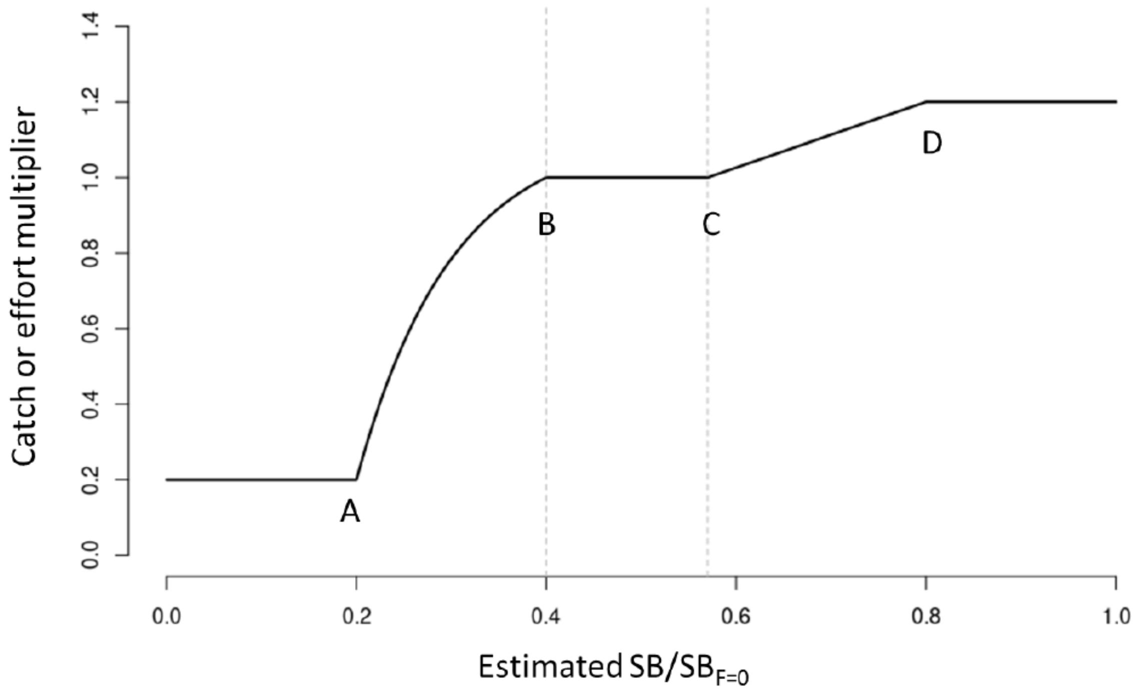

FIGURE 3. Harvest control rule adopted for the WCPFC skipjack tuna harvest strategy (from CMM 2022-01).

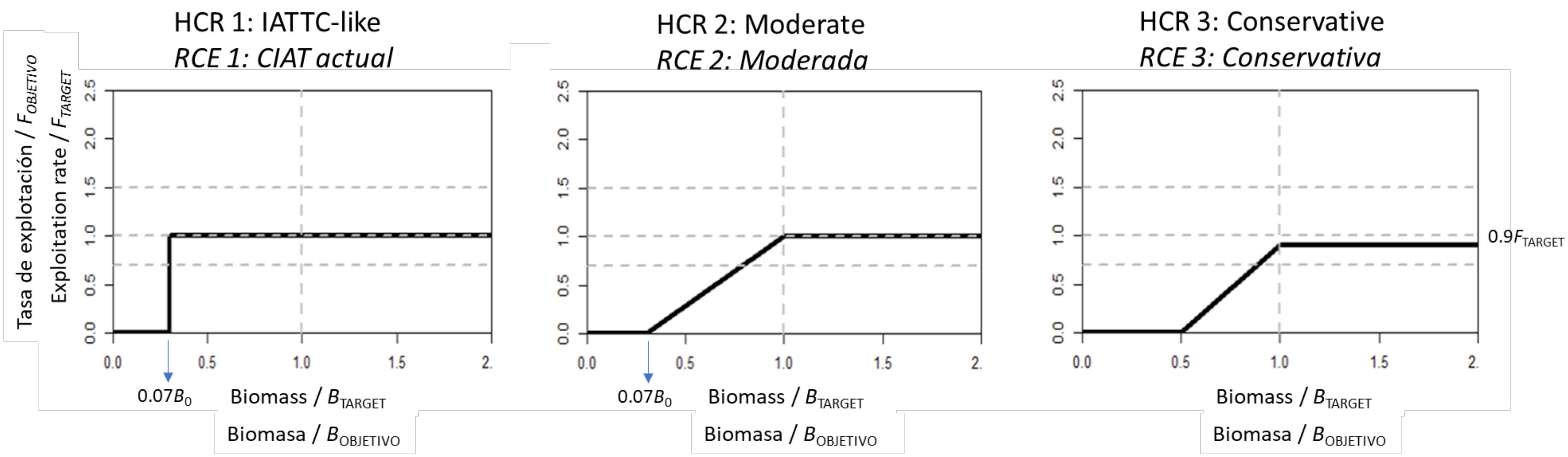

FIGURE 4. Alternative Harvest Control Rules (HCR) discussed during the 3rd IATTC Workshop on tropical tuna MSE as candidates for evaluation during the bigeye tuna MSE. B_{TARGET} and F_{TARGET} are either MSY-based quantities or $B_{30\%}$ and $F_{30\%}$. (from SAC-15-07).