Management benchmarks, reference points and Management Strategy Evaluation for IOTC stocks

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Introduction

Tunas sustain some the of world's most valuable fisheries and dominate marine ecosystems worldwide [1]. The management of tunas is responsibility of tuna Regional Fishery Management Organizations (tRFMO), including the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), and the Western Central Pacific Fisheries Commission (WCPFC). Since their foundation, tuna RFMOs have aimed at achieving the maximum sustainable yield (MSY), an equilibrium point at which the capacity of fish stocks to replace the harvested biomass is maximized and, therefore, fisheries' long-term average catch is maximized too. MSY has represented the benchmark on which many fisheries agencies have developed their management frameworks, including tRFMOs. In general, maximizing catch has been considered a management objective and, the biomass and fishing mortality at MSY (B_{MSY} and F_{MSY}) have been the benchmarks that have guided fisheries management. The development of fisheries policy and the adoption of management measures needs to be guided by scientific advice, and, in fisheries, this is done through fisheries' stock assessment. Stock assessments evaluate changes in the abundance of fish stocks in response to fishing and it is the technical tool used to estimate the state of exploitation of fish stocks. The output of fishery stock assessments includes estimates of biomass and fishing mortality and their values associated to the MSY benchmark. B_{MSY} and F_{MSY} have been the references used to determine if a stock is considered '*overfished*' ($B<B_{MSY}$) or '*subject to overfishing*' ($F>F_{MSY}$). Based on this, fishery management agencies have developed management frameworks to restore or maintain stocks at or above the B_{MSY} and fishing mortality at or below F_{MSY}. To sum up, the management objective in tuna RFMOs is to maximize catch in a sustainable manner and, MSY, B_{MSY} and F_{MSY} have been the benchmarks used to characterize stock status and guide the management actions towards the management objective.

Mathematical models such as the models used in stock assessment can never describe a system with certainty. It is understood that the causes of uncertainty in fish stock assessments and risk in fisheries management are: observation errors (linked to the quality of data), model errors (due to the limited ability of models to reproduce population dynamics patterns) and process errors (due to the lack of understanding of the biological processes underlying fish stock dynamics) [2]. The Precautionary Approach (PA) aims at improving the management of fish resources and to avoid undesirable situations considering that changes in fishery systems are not well understood and seeks to protect fish stocks from fishing practices that may put their long-term viability in jeopardy despite the many unknowns on stocks biology, response to fishing, or exact state of exploitation [3]. The PA calls for fisheries management institutions to address uncertainty by the determining the status of fish stocks relative to target, threshold and limit reference points and to characterize the uncertainty in fish stock assessments. Target reference points (TRP) are a benchmark that should be achieved on average, according to a set

of management objectives, and limit reference points (LRP) are benchmarks that should be avoided with substantial probability. LRP indicate the limit beyond which the state of a fishery and/or a resource is considerable not desirable and remedial action is required to allow recovery. Precautionary threshold RPs are used to determine the actions to avoid reaching the LRP. The references to reaching the TRP "on average" and avoiding the LRP with "substantial probability" requires that management frameworks define what they consider high, low or substantial probability and the timeframes to react to overfishing and recover stocks to levels above the B_{MSY}. The PA also requires analysists to represent the outcome of stock assessments using probability distributions to characterize the uncertainty inherent to each fishery. Therefore, it is a common practice to express the status of stocks in probabilistic terms in stock assessments.

One way to address the uncertainty in fisheries from the PA is the adoption of management procedures (MP), also known as harvest strategies (HS), that aim at both achieving a low probability of breaching safe biological limits (LRP) and providing high average long-term catch and fisheries performance [4]. HS can be designed to specify changes to catch limits, or any other measure, based on updated monitoring data and methods of analysis. Adopting a HS requires specifying the management objectives (probabilities, timeframes and risk), reference points (TRPs and LRPs), performance indicators to monitor how effective the management measure is, the data and methods of analysis to determine the current state of the resource, and a decision rule (or harvest control rule, HCR) based upon the estimated state of the stock (including fishery indicators). The adoption of MPs is the result of a process known as Management Strategy Evaluation (MSE) which includes a dialogue and consultation between the stakeholders of a fishery and the development of numerical models. The dialogue and consultation process aims at defining the management objectives, reference points, mechanisms on which the fishery will be managed and the performance metrics to be used to evaluate the performance of alternative MPs. The numerical framework is developed to provide responses to the requests of stakeholders and to evaluate the conservation and economic implications of the adoption of a range of MPs that are built based on the agreed management objectives and RPs.

The IOTC has followed its own process towards the adoption of MPs. In 2016, the IOTC adopted a HCR for the management of Indian Ocean skipjack [5] and established a Technical Committee on Management Procedures (TCMP) [6] to guide the Commission in the MSE process towards the adoption of MPs, which are expected for 2022, 2023 and 2024 for the most important tuna stocks (albacore, skipjack, yellowfin, bigeye and swordfish) [7, 8]. The TCMP noted that further work is required on understanding the determination of stock status relative to Reference Points and an *Ad-hoc Reference Point Working Group* was formed for that purpose (IOTC Circular 19-30). Specifically, this ad-hoc working group is established to provide information to the TCMP on issues relating to the definition and presentation of stock status against conservation and management reference points. In this document, we review the reference points and the management framework currently in force in the IOTC and provide insights on its possible improvements and alternatives for further developing target and limit reference points and general recommendations for the adoption of MPs.

The IOTC management framework and benchmarks for management

The objectives of the IOTC include ensuring, through appropriate management, the conservation and optimum utilization of stocks and encouraging the sustainable development

of fisheries based on such fish stocks. For this, the IOTC follows the guidelines and recommendations of the Kobe framework [9], an initiative that aims at providing consistency of advice across tuna RFMOs (IOTC Res. 15/10). Under this framework (Figure 1 left), the status of fish stocks is characterized relative to their MSY benchmarks (B_{MSY} and F_{MSY}). This way, with the exception of skipjack after Resolution 16/02, a tuna stock in the IOTC is considered to be "overfished" if its biomass is estimated to be below the biomass at MSY ($B<B_{MSY}$) and "subject to overfishing" if the fishing mortality is estimated to be larger than the fishing mortality at MSY ($F>F_{MSY}$). Since the adoption of the Kobe framework, the IOTC adopted the management objective of maintaining tuna stocks in the green area of the Kobe plot (not overfished ($B>B_{MSY}$) and not subject to overfising ($F<F_{MSY}$)) with high probability in Resolution 15/10. For stocks that are overfished and/or subject to overfishing, the IOTC Res 15/10 requires to end overfishing with high probability and rebuild the stock to B_{MSY} in as short a period as possible. However, the specific probability and timeframes for have not been adopted yet [10].

The Kobe framework is not the only management scheme used in tuna RFMOs. The WCPFC management is based on a framework that represents biomass relative to fish stocks biomass (or spawning biomass) depletion (B/B_0 or SB/SB_0) and fishing mortality relative to F_{MSY} (Figure 1 right). Under this framework, the MSY-based benchmark of fishing mortality is combined with a depletion-based benchmark, the 20% of SB0, which is also the LRP. Under the Majuro framework, a stock is considered to be "overfished" if the spawning stock biomass is estimated below the LRP ($0.2xSB_0$) and "subject to overfishing" if the fishing mortality is larger than F_{MSY} ($F>F_{MSY}$).

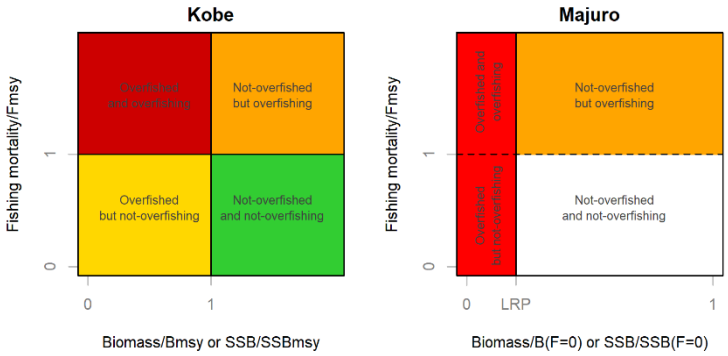

Figure 1. Management framework and sustainability benchmarks used in tuna RFMOs (Kobe is used in ICCAT, IOTC, IATTC and CCSBT), Majuro is used in the WCPFC and CCSBT).

Both the Kobe and Majuro management frameworks consider undesirable that fishing mortality is at levels larger than F_{MSY} and treat it as a limit. when this is detected, both frameworks recommend reducing fishing mortality in the shortest possible time. However, Kobe and Majuro have a different benchmarks to catalogue a fish stock as "overfished". In the Kobe framework, if the estimation of an overfished state ($B<B_{MSY}$) will automatically recommend restoring the stock towards B_{MSY} in the shortest possible time. The Majuro framework will recommend this when the stock is estimated to be below the 20% of depletion, which it is considered the level at which recruitment failures are thought to become increasingly likely and that the stock is outside safe biological limits. In this situation, a drastic management measure may be necessary. Under Kobe, the call for management action is made before the stock reaches the LRP*.

* Note that this general conclusion has its exception too: There are stocks where the B_{MSY} is estimated to be at levels lower than the LRP (e.g. Pacific swordfish).

Depletion based and MSY-based Reference Points

As a first step towards the adoption of MPs the IOTC adopted interim target and limit Reference Points for its most important tuna stocks in 2015 [11] (Table 1).

Stock	Target Reference Point	Limit Reference Point
Albacore Yellowfin tuna Swordifsh	$B_{TARGET}=B_{MSY}$ $F_{TARGET}=F_{MSY}$	$B_{LIM}=0.40xB_{MSY}$ $F_{LIM}=1.40xF_{MSY}$
Bigeye tuna		$B_{LIM}=0.50xB_{MSY}$ $F_{LIM}=1.30xF_{MSY}$
Skipjack tuna		$B_{LIM}=0.40xB_{MSY}$ $F_{LIM}=1.50xF_{MSY}$

Table. 1. Interim target and limit reference points adopted in the IOTC (Resolution 15/10).

The target and limit RPs for skipjack were replaced in 2016 due the difficulties estimating the MSY-based reference points. Instead, the IOTC adopted Resolution 16/02 with a new set of RPs for skipjack which are not based on MSY but in the depletion level of the stock (biomass relative to its pristine state (SB_0)). The current values for skipjack are $TRP=0.4xSB_0$ and $LRP=0.2xSB_0$. The adoption of the TRP was based on the idea that this value represents a valid proxy for B_{MSY}.

There are two main differences between the Kobe and the Majuro management frameworks and RPs that can be derived from them:

i. *Depletion based vs MSY-based biological benchmarks.* There are advantages and disadvantages of using the two approaches for setting benchmarks and reference points. The strength of MSY is that it includes fish stocks' productivity directly and it is incorporated into many of the legal frameworks of highly migratory fisheries (e.g. UNCLOS (1982), UNFSA (1995) and the foundational objectives of tuna RFMOs). The key weakness is the difficulty in estimating MSY-based RPs robustly across models and methods. This is because MSY is sensitive to uncertainties on the steepness of the stock-recruitment relationship and fisheries selectivity by age, which tend to be highly uncertain components of stock assessments. Depletion estimates provide information on how much the SSB has been reduced since the fishery began and therefore, how much SSB remains, and the estimated impact on historic, current and future recruitment and yield. An advantage of depletion based RPs is that they are relatively stable between assessments and, in many of the tuna stocks have provided the least variation in the range of results across a range of steepness values used [12].

ii. *How and when management action is recommended.* Under the Majuro framework, if the stock is estimated to be below the LRP, severe management action will be recommended, but if not, the fishery will be modulated looking at the fishing mortality only. The general recommendation under the Majuro framework is to maintain the fishing mortality below the F_{MSY}. Under the Kobe framework, management action will be recommended also in cases where fishing mortality is lower than F_{MSY} if biomass is also below the B_{MSY}. The level of fishing mortality reduction required to restore the stock to levels at or above B_{MSY} will depend on the timeframes adopted by the management agencies. Under the Kobe framework, the RFMO science providers will develop Kobe II Strategy Matrices that estimate the

probability of recovering the stocks towards the B_{MSY} at different levels of fishing mortality and timeframes. The advice on the WCPFC based on the Majuro plot is based on the difference between the estimated fishing mortality and FMSY, in cases where the stock is above the LRP.

The adoption of one or the other RPs and associated benchmarks needs to be discussed at Commission level but the SC can provide advice. One way to address this issue is to assign the Kobe framework for stocks for stocks that are not managed using MPs or HCRs and to adopt the Majuro framework for stocks where the MP and HCR will recommend management action before the LRP are breached. This way, management action will be recommended when the stock is below B_{MSY} and/or fishing mortality is larger than F_{MSY} when there is no MP adopted (e.g. Indian Ocean yellowfin, bigeye, swordfish and albacore) and when the fishery is managed through a MP (or HCR), fisheries management will be modulated by the adopted mechanism (e.g. catch limits established for Indian Ocean skipjack).

Management objectives, benchmarks, reference points and Management Strategy Evaluation: The case of Indian Ocean skipjack

The overarching principles of fisheries agencies result in management objectives, which are monitored using benchmarks. In the MSE process, management objectives are used with reference points, performance metrics and specific probabilities to evaluate and fine tune candidate Management Procedures (MP). First, TRPs can be used to set the levels of biomass and fishing mortality that can be achieved on average by each candidate MP. Second, TRP and LRP are often used as coordinates of Harvest Control Rules (HCR) that are built within MPs to describe the management reaction to the state of fish stocks. For example, in the HCR adopted for North Atlantic albacore (Figure 2), the coordinates of the HCR are named as F_{TARGET} , F_{MIN}, B_{LIM} and $B_{THRESHOLD}$ [13]. In this case the adopted LRP is also the coordinate B_{LIM} and the fishing mortality target is also part of the HCR. In this HCR, both the benchmark and the management objective are consistent (both based on probabilities of achieving MSY-based levels) with the Kobe framework. However, this is not always the case and special focus needs to be placed on the differences between management objectives, benchmarks, reference points and the coordinates of model-based MPs or HCRs.

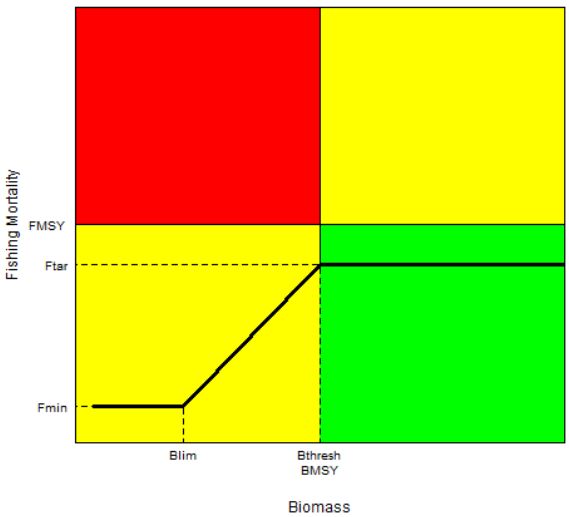

Figure 2. Harvest Control Rule adopted for North Atlantic albacore.

The application of Resolution 21/03 on the HCR for Indian Ocean skipjack is an example of the lack of clarity of these concepts in the MSE process. Resolution 21/03 describes the management objective for this stock as to maintain the stock at levels at or above the B_{MSY} (paragraph 1) but also to maintain the stock at or above the TRP which is set at 40% of SB_0 and well above the LRP (paragraph 2). The reason for this double objective was the difficulty in estimating the MSY-based RPs for this stock at the time of the Resolution. The value of 40%SB_0 was used as a proxy of B_{MSY}, and it is also the benchmark used to characterize if the stock is overfished or not. If MSY-based RPs could not be estimated it seems reasonable to use the TRP as a benchmark, if this was considered a valid proxy of B_{MSY}. However, the latest assessments of Indian Ocean skipjack have been proven able to estimate MSY-based RPs with reliability. In the last two assessments, in 2017 and in 2020, the B_{MSY} was estimated to be on average at 23% of B_0. In 2017, the stock was assessed exactly at its TRP, i.e. the average biomass was estimated to be at 40% of SB_0 and between 1.25-2.35xSB_{MSY}. In 2017, the management objectives for this stock were fully achieved because the probability of being below the LRP was 0 and the TRP had been achieved on average (paragraph 2 of Resolution 16/02). However, the IOTC SC assigned a 49% probability for the stock to be overfished. This is because the TRP was also used as a benchmark. The adopted HCR for skipjack has been evaluated to maintain the stock at levels above the LRP with high probability and the TRP is set at biomass levels higher than B_{MSY} (despite the original intention to be a proxy of B_{MSY}). The maximum fishing mortality used in the HCR ($F_{40\%SB0}$) is implicitly the fishing mortality target, which is also lower than F_{MSY}. The main aspect that may need adjusting is the benchmarks used to evaluate its performance and monitor the status of the stock. Today, estimating MSY-based benchmarks is possible for skipjack and it seems reasonable to characterize the status of the stock based on these. Resolution 21/03 notes that the SC at its 17th edition, recommended the Commission consider limit reference points around MSY when MSY-based reference points can be robustly estimated, which may be contradictory with the adoption of the 40%SB_0 as a proxy for B_{MSY} as a TRP and the TRPs adopted in Resolution 15/10. The interpretation of paragraphs 1 and 2 of Resolution 21/03 also suggest that when MSY-based reference points can be robustly estimated the management objective will be to maintain skipjack at levels not less than those capable of producing the MSY. Noting the the TRP is currently set at levels larger than B_{MSY} it seems reasonable to maintain the HCR as it is (TRP=40% SB_0) to increase the probability of being above the B_{MSY} benchmark, but to use the B_{MSY} as the benchmark to categorize the stock as "overfished" and the F_{MSY} to consider it "subject to overfishing".

Noting that the biological and fishing mortality TRPs are expressed in terms of depletion level, it may also seem reasonable to adopt the Majuro framework, and evaluate the status of the stock based on the biomass depletion and fishing mortality relative to F_{MSY} and to characterize the stock as overfished when it falls below the LRP. As said earlier, the adopted HCR provides the framework that will recommend management action when the stock is estimated to be below the TRP (Figure 3), but it doesn't seem reasonable to assign a 49% probability of overfished status to a stock that is estimated to be exactly at the target reference point (on average), that is estimated well above the B_{MSY}, with fishing mortality lower than F_{MSY} and with 0 probability of being below safe biological limits (LRP). In the 2020 assessment of the skipjack the categorization of the stock was provided in four categories (Executive Summary, Appendix X SC report): (i) above/below the biomass target reference point, (ii) **overfished** (SB_{2019}<$SB_{40\%SB0}$) **or not overfished** (SB_{2019}>$SB_{40\%SB0}$); with fishing mortality above/below the adopted target reference point, and; (iv) **subject to overfishing** (E_{2019}>$E_{40\%SB0}$) or **not subject to overfishing** (E_{2019}<$E_{40\%SB0}$). We note that these four categories are repetitive and suggest to categorize the stock as: (i)

above/below the biomass target reference point, (ii) **overfished** ($SB_{2019}<SB_{MSY}$) **or not overfished** ($SB_{2019}>SB_{MSY}$); with fishing mortality above/below the adopted target reference point, and; (iv) **subject to overfishing** ($F_{2019}>F_{MSY}$) or **not subject to overfishing** ($F_{2019}<F_{MSY}$). In other words, to use the MSY benchmarks to categorize skipjack as overfished or subject to overfishing. We also recommend that the color code is adapted to the MSY benchmark following the Kobe plot to be consistent with the other stocks of the IOTC. We also note that using the Majuro framework based on F_{MSY} and SB/SB_0 and defining "overfished" as when the stock falls below the LRP would be a reasonable option noting that the management action is called when the stock falls below the TRP after Resolution 21/03.

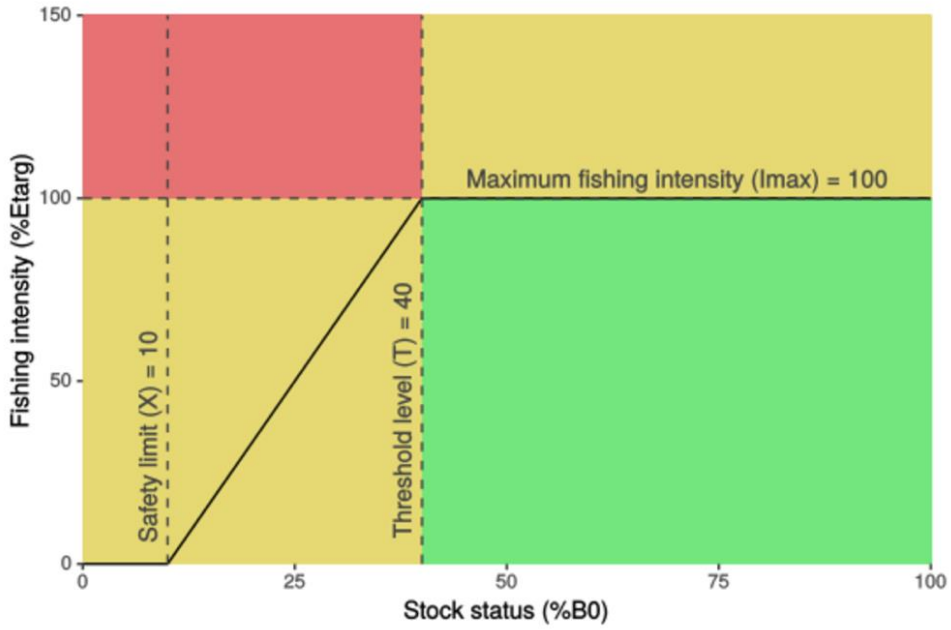

Figure 3. HCR adopted for Indian Ocean skipjack (Resolution 16/02).

Discussion and potential recommendations

The commitment of tuna RFMOs to the MSE process and to the adoption of MPs requires the clarification of terms like management objectives, management benchmarks, probabilities and timeframes, reference points and the coordinates of MPs. This document aims at reviewing some of these concepts and raise discussions in the Ad-hoc Reference Point Working Group, the MSE task force and the TCMP.

- There are two management frameworks in use in tuna RFMOs and we acknowledge that it is possible to develop different ones that include buffer zones or different color-codes. However, it is essential that the benchmarks used to characterize stock status are agreed and it is understood that they don't necessarily need to be the same as the target or limit RPs or the reference thresholds or coordinates of model-based HCRs and MPs.
- Once MPs are adopted for all stocks it may be a good moment to decide the general management framework for the IOTC. Until MPs are adopted it may be a good option to use the Kobe framework (based on MSY benchmarks) and to use the Majuro framework (based on depletion-based LRP and F_{MSY}) for stocks where HCRs or MPs are adopted.

- MSY benchmarks (B_{MSY} and F_{MSY}) can be used to characterize stock status because they are consistent with the general objectives of the IOTC.
- In cases where the MSY-benchmarks cannot be estimated, depletion based TRP or LRP are alternatives that could be used to define if the stock is overfished or subject to overfishing. If the benchmark to define overfished is to be set at the TRP, it will be necessary to ensure that it is a valid proxy of B_{MSY}. If not, using the biological LRP to define overfished status and the target fishing mortality to define overfishing could be a good alternative.
- The coordinates of HCRs and MPs may or may not be coincident with the benchmarks and reference points adopted for the stock. It is important to clarify that often the names of these are used indistinctively but they can be different.
- The coordinates of model-based HCRs and MPs should consider F_{MSY} as a limit, a value that will not be exceeded to ensure that the stock will be maintained or recovered above B_{MSY} levels with more than 50% probability.
- Noting that both MSY and depletion based RPs can be calculated for skipjack, the benchmark used to categorize the stock as "overfished" and colour code should be based on the LRP (Majuro framework) or B_{MSY} (Kobe framework). The stock can also be categorized as above or below the target reference points.

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