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Is my red the same as your red? Improving the communication of stock status and support for management in the Indian Ocean Tuna Commission with specific recommendations for Indian Ocean skipjack

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ABSTRACT

Fisheries management is based on the status of fish stocks and the scientific advice developed from stock assessments. Scientific advice is communicated using tables and figures and is often summarized using colors, which are a powerful tool to communicate information and trigger decision-making. However, a common understanding of what colors and stock status categories represent is necessary to ensure the adoption of scientifically sound management measures. We show that the characterization of the status of Indian Ocean skipjack tuna stock is flawed due to the inconsistent combination of overarching fishery principles (maximum use of stocks' productivity and reduction of risk) and the inaccurate representation of the scientific evidence available from recent stock assessments. Furthermore, we discuss how the general principles of fisheries management are applied in tuna RFMOs and propose a way forward for improving the communication of the status of tuna stocks in general. This discussion paper is specifically focused on Indian Ocean skipjack and aims at improving the management framework of the Indian Ocean Tuna Commission. However, our conclusions are applicable to fisheries management worldwide.

1. Introduction

Colors are a powerful tool for communication and play an important role in conveying information, evoking psychological responses and influencing decisions [1]. In the realm of fisheries science and management, colors represent fish stock status to indicate exploitation levels and trigger management actions when needed [2]. However, inconsistencies in the use of management principles and concepts can lead to flawed communications of the status of fish stocks. To avoid this, a common understanding of color representations, stock status categories and the different components of scientific advice is vital. This document highlights this issue with Indian Ocean skipjack, where the Indian Ocean Tuna Commission (IOTC) has adopted reference points, management objectives, and a comprehensive harvest strategy or management procedure [3].

2. The components of a fisheries assessment and management framework

International initiatives for fishery governance, such as the *United Nations Sustainable Development Goal* (SDG) number 14 *to conserve and sustainably use the oceans, seas and marine resources for sustainable development*, the *FAO status of fishery resources*, and agreements like UNCLOS, UNFSA, and the conventions of tuna RFMOs, are built upon the maximum productivity of fish stocks, known as *Maximum Sustainable Yield* (MSY). Defined by W.E. Ricker as "*the largest average catch or yield that can be continuously taken from a stock under existing environmental conditions*" [4], MSY represents the equilibrium point where fish stock replacement and long-term average catch are maximized [2]. If we were to draw an analogy between a Greek building and the scientific advice for fisheries management, the foundation would be the MSY or the productivity of the stocks (Fig. 1).

Maximum Sustainable Yield (MSY) is calculated through fishery

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Fig. 1. The "building" of the scientific advice for fisheries management.

stock assessments. These models also estimate exploitation rates and forecast sustainable catch limits. The key pillars of communicating the outcome of these assessments and scientific advice are reference points, stock status categories (colors), and their probabilities (Fig. 1). Reference points are employed to assess the status of fisheries in terms of biomass and fishing mortality, either relative to an optimal state (target reference points) or a state deemed undesirable or a level of exploitation that should be avoided (limit reference points).

Most global management frameworks use MSY as a reference [5], including those from FAO, ICES [6], EU Common Fishery Policy (CFP) [7], US Federal Fisheries Management [8], Canada's Sustainable Fisheries Framework [9], Australia's Commonwealth Fisheries Harvest Strategy Policy [10], and New Zealand's Fisheries Act and Management Framework for 2030 [11]. FAO defines a biologically sustainable stock when its biomass is above 80 % of B_{MSY}. ICES aims to inform policies for high, long-term yields while maintaining productive fish stocks that meet environmental standards. The EU CFP aims at reaching MSY for all target stocks with an operational, measurable, and science-based objective for fisheries management. Both the US and Canada place MSY achievement upfront, defining overfishing and stock status zones based on MSY. However, Australia and New Zealand (and WCPFC) have replaced MSY and its associated biomass by a proxy as a reference (see 3).

Tuna RFMOs use MSY benchmarks of biomass (B_{MSY}) and fishing mortality (F_{MSY}) (or proxies) to assess stock status. For example, stocks are categorized by the Indian Ocean Tuna Commission (IOTC) as: *Not overfished and not subject to overfishing* (Biomass (B)> B_{MSY} and fishing mortality (F) <F_{MSY}), *not overfished but subject to overfishing* (B>B_{MSY} and F>F_{MSY}), *overfished but not subject to overfishing* (B<B_{MSY} and F<F_{MSY}) and *overfished and subject to overfishing* (B<B_{MSY} and F>F_{MSY}). These four categories are represented with colors using figures known as Kobe diagrams (Fig. 2).

Fishery stock assessments use assumptions on key biological processes such as growth, reproduction, and natural mortality, as well as fishery data. However, the available data and studies to support assumptions about these components are generally limited [12,13]. Therefore, categorizing stock status into four groups may not suffice to trigger management actions, hence probabilistic estimates are used to represent the uncertainty of the results. For instance, Fig. 3 shows the stock status for two theoretical stocks; both are overfished and subject to overfishing on average (red color), but their probabilities suggest different levels of urgency for management action. It underscores the importance for fishery managers to understand these probabilities alongside stock assessment results.

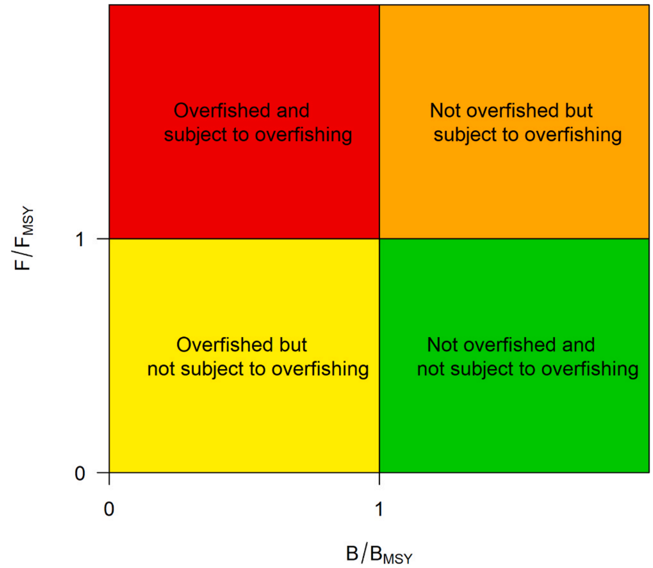

Fig. 2. Fisheries management framework based on MSY benchmark, as used in the IOTC, ICCAT and others.

The Precautionary Approach (PA) for fisheries management aims to safeguard fish stocks from fishing practices that may compromise their long-term sustainability despite numerous uncertainties about stock biology, response to fishing, or exact exploitation status [14]. The PA advises addressing uncertainty by assessing fish stocks against target, threshold, and limit reference points, predicting the results of management alternatives to meet targets and avoid limits, and characterizing the uncertainty in both scenarios using probabilities [15]. Limit Reference Points (LRP) are levels that should be avoided with high probability. Target Reference Points (TRP) are levels that should be achieved on average and represent a desirable state of fishery and have explicitly been adopted by IATTC and IOTC for their key tuna stocks (see IOTC's Resolution 15/10 and IATTC's Resolution 23/06).

To assist managers in selecting catch limits that meet management objectives within different timeframes, risk assessments are used. In the IOTC and other tuna RFMOs, these projections are developed from stock assessment models with various fixed catch levels. Results are summarized using Kobe II Strategy Matrices (K2SM), which report the probability of achieving TRP or breaching LRPs under different fisheries management scenarios [16]. Table 1 displays the K2SM for Indian Ocean yellowfin assessed in 2021 [17].

We note that the adoption of Harvest Strategies or Management Procedures (MP) will update the generic management frameworks in tuna RFMOs. MPs involve a series of pre-agreed actions to monitor, assess, manage, and implement advice for stock. With an MP, management advice will be based on the MP rather than probabilities from stock assessment models. However, stock assessments will still be used to categorize the status of fish stock periodically.

3. Alternatives to MSY and MSY as a limit

The management framework of the IOTC aligns with international legal frameworks, which are based on fish stock productivity (or MSY) and precautionary principles. Other frameworks have adapted their interpretation of MSY for scientific reasons [18]. For instance, the management frameworks in Australia, New Zealand and the WCPFC outline management targets beyond the deterministic MSY thresholds, assuming that MSY benchmarks calculations are unrealistic [19]. Larkin in 1977 indicated that fish population dynamic models oversimplify the actual dynamics of fish stocks and overlook significant uncertainty in the stock-recruitment relationship for exploited stocks, making MSY, F_{MSY},

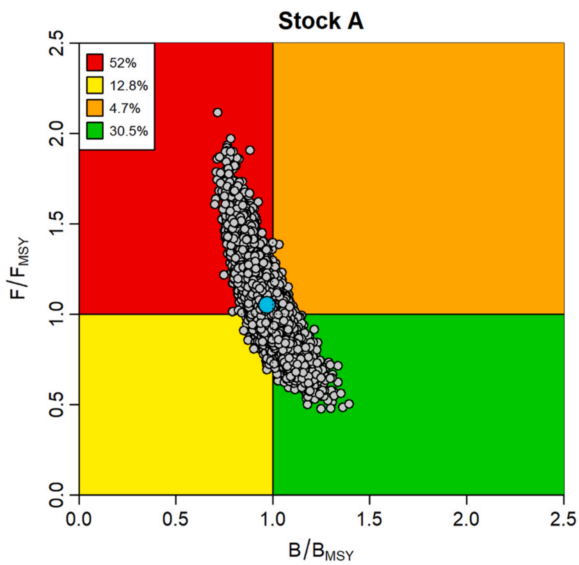

Fig. 3. Graphical representation of the estimated stock status for two theoretical stocks using probabilities. Light blue represents the average stock status.

Table 1
Yellowfin tuna: Stock synthesis assessment Kobe II Strategy Matrix. Probability of violating the MSY-based target (top) and limit (bottom) reference points for constant catch projections (relative to the catch level from 2020 % to 40 %, - 30 %, −20 %, −10 %, 0 %, +10 %, +20 %) projected for 3 and 10 years. Extracted from the IOTC's Scientific Committee report (IOTC, 2021, IOTC–2021–SC24–R[E]).

Alternative catch projections (relative to the catch level from 2020) and probability of violating MSY-based target reference points ($SB_{targ} = SB_{MSY}$; $F_{targ} = F_{MSY}$)							
Reference point and projection timeframe	60 %	70 %	80 %	90 %	100 %	110 %	120 %
$SB_{2023} < SB_{MSY}$	0.45	0.56	0.68	0.74	0.76	0.82	0.88
$F_{2023} > F_{MSY}$	0.13	0.30	0.53	0.63	0.72	0.82	0.91
$SB_{2030} < SB_{MSY}$	0.1	0.33	0.54	0.76	0.93	0.99	1
$F_{2030} > F_{MSY}$	0.07	0.31	0.49	0.69	0.84	0.97	0.99
Alternative catch projections (relative to the catch level from 2020) and probability of violating MSY-based limit reference points ($SB_{lim} = 0.4\ SB_{MSY}$; $F_{Lim} = 1.4\ F_{MSY}$)							
Reference point and projection timeframe	60 %	70 %	80 %	90 %	100 %	110 %	120 %
$SB_{2023} < SB_{Lim}$	0	0	0	0.05	0.07	0.1	0.16
$F_{2023} > F_{Lim}$	0.03	0.11	0.25	0.43	0.52	0.63	0.78
$SB_{2030} < SB_{Lim}$	0	0	0.01	0.18	0.64	1	1
$F_{2030} > F_{Lim}$	0.02	0.19	0.33	0.60	0.78	0.98	0.98

and B_{MSY} estimates unreliable [20]. Consequently, a conservative proxy of B_{MSY} at 20 % of the unfished biomass (20 % B0 or 20 % $B_{F=0}$) is often used to assess the status of stocks, utilizing a different color palette and using limits instead of targets as benchmarks (Fig. 4). This management framework seeks to reduce risks associated with the limited understanding of fish stocks' response to harvesting rather than maximizing the theoretical productivity of the stocks.

In reality, the frameworks shown in Fig. 2 (used in IOTC and others) and Fig. 4 (used in the WCPFC) are not that different: both systems categorize the status of the stock estimating biomass and fishing mortality relative to the biomass at MSY or a proxy (20 %B_0) (Table 2). Both systems identify a stock as overfished if it is below B_{MSY} or the proxy of 20 %B_0. However, they differ in interpreting the risk of breaching limit reference points and defining target reference points. MSY-based LRPs (e.g. 0.3–0.5 of B_{MSY}) allow lower risk acceptance, while using 20 % B0 as a proxy might accept higher risk levels. Consistency in understanding the principles (maximum use of stocks' productivity and reduction of risk), reference points, colors, and probabilities within each framework is crucial, a lesson learned from the Indian Ocean skipjack management.

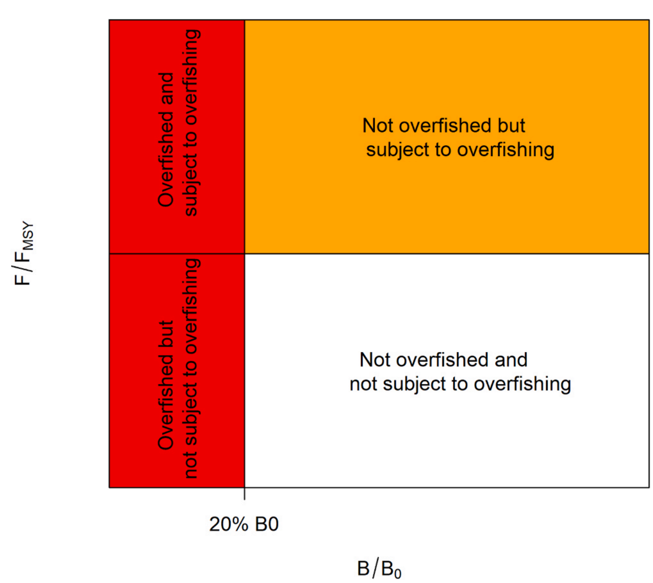

Fig. 4. Fisheries management framework based on F_{MSY} and depletion levels (ratio of B_0) and benchmark at 20 % of B_0, as used in the WCPFC and others.

4. The case of Indian Ocean skipjack

The IOTC has improved its management framework by adopting management objectives, reference points, probabilities, harvest control

Table 2
Benchmarks currently in use to categorize a stock as "overfished" in tuna RFMOs and for the particular case of Indian Ocean skipjack in the IOTC (in bold). B denotes biomass or spawning stock biomass.

RFMO	Stock	Basis of framework	Current threshold for stock status categories	Criteria for "overfished"
ICCAT	All	MSY	B_{MSY} – F_{MSY}	B<B_{MSY} (TRP)
IOTC	All except IO skipjack	MSY	TRP (B_{MSY} – F_{MSY})	B<B_{MSY} (TRP)
	IO skipjack	**Depletion (% of B0)**	**TRP (40 %B_0 – $F_{40\ \%B0}$)**	**B< 40 %B_0 (TRP)**
IATTC	All	MSY	TRP (B_{MSY} – F_{MSY})	B<B_{MSY} (TRP)
WCPFC	All	Depletion (% of B0)	LRP (20 % $B_{F=0}$ – F_{MSY})	B< 20 % $B_{F=0}$ (LRP)

rules, and management procedures for its key tuna stocks. This includes a Harvest Control Rule for Indian Ocean skipjack (Resolution 16/10, superseded by Resolution 21/03), and a comprehensive MP with probabilities for achieving targets and avoiding limits (Resolution 24/04). However, inconsistencies in the interpretation of reference points and the misguided combination of MSY-based and depletion-based principles have resulted in specific problems in the management framework for this stock. But let's start from the beginning:

In 2015, the IOTC adopted Resolution 15/10 on target and limit reference points. Implicitly, the management objectives were to keep biomass at or above B_{MSY} and fishing mortality at or below F_{MSY}, ensuring stocks remain in the green quadrant of the Kobe plot or recover in a period as short as possible. TRPs were set at B_{MSY} and F_{MSY}, making MSY the basis of its management framework and aiming to maximize catch. LRPs were set relative to MSY at 0.4–0.5xB_{MSY} and 1.3–1.5xF_{MSY}. Res 15/10 also specifies that if MSY points cannot be estimated, TRPs will be based on levels of unfished biomass (B0), with LRPs set at 20 % B_0 and $F_{20\ \%B0}$.

The 2014 assessment of Indian Ocean skipjack had an error in the selectivity of age 0 fish, making MSY estimates potentially unreliable [21]. This, and the fact that skipjack is a fast-growing species that reaches maturity at very early ages were the reasons for adopting reference points based on depletion (B_0) and not B_{MSY} for skipjack (TRP=40 %B_0 and LRP=20 %B_0). After correcting the selectivity issue, MSY benchmarks for this stock were estimated and B_{MSY} estimates range between 17 % and 26 % of B_0, well below the adopted TRP of 40 % B_0. It is important to note that in the other tuna RFMOs (ICCAT, IATTC and WCPFC), there is no difference in the management framework of skipjack relative to the other stocks.

The current scientific advice and management framework for Indian Ocean skipjack is flawed due the inconsistent combination of fishery principles. Using the management framework of the WCPFC (which aims at minimizing risk by setting MSY proxies as LRPs at 20 %B_0), adopting TRPs beyond B_{MSY} (e.g., 40 % B0) is reasonable (as done for Indian Ocean skipjack and for several tuna stocks in the WCPFC). A stock that on average is at 40 % B0 (TRP) will be *not-overfished* with a probability of more than 50 % because it will be (on average) twice as abundant than the LRP benchmark of 20 % B0 used in the WCPFC to categorize the stock as overfished. However, IOTC's adopted way to standardize the presentation of scientific advice (Resolution 14/07) recommends expressing stock estimates relative to the TRPs. This is reasonable with MSY-based RPs but not if the TRP significantly differs from MSY or its proxies. For instance, a stock at the TRP of 40 % B0 on average would be considered overfished with a 50 % probability under Resolution 14/07 despite being twice the proxy of B_{MSY} (20 % B0).

This is exactly what has been happening with Indian Ocean skipjack since 2017 (Table 2). The median biomass for the stock was estimated at 40 %, 45 %, and 53 % of B0 in the last three assessments (2017, 2020, and 2023, respectively) [22–24]. This corresponds to 167 %, 199 %, and 230 % of the estimated B_{MSY}. The probability of breaching the LRP of 20 % B0 was 0 % each time. However, stock status (colors) have been communicated using a Kobe plot based on the TRP (40 %B0) as per IOTC Recommendation 14/07. Under the current framework, the probabilities of being overfished and subject to overfishing (red color in the Kobe plot) were 38 %, 19.5 %, and 8 %, indicating less optimism about stock status than would be expected for a stock at the estimated high levels of biomass. In 2020 and 2023, the stock was above the TRP, but in 2017, it was estimated exactly at the TRP, with an associated ~50 % probability of being overfished (Fig. 5). Since the error in the selectivity of age 0 was identified and MSY-based RPs can be estimated at least with the same levels of robustness as for other stocks, the SC recommended reviewing the use of depletion-based or MSY-reference points for this stock in 2023 [24]. And hence, our proposal.

5. A way forward for the IOTC

Maintaining a fish stock at the TRP while achieving a low probability of overfishing is incompatible if the characterization of status is based on the same TRP. If the TRP is set at MSY (B_{MSY} and F_{MSY}), reaching it on average means a 50 % chance of being overfished, which isn't low. For Indian Ocean skipjack, where the TRP surpasses B_{MSY}, the benchmark used to categorize the stock as overfished should be based on B_{MSY} or a proxy such as 20 % B_0.

There are two ways to build up the current management framework within the IOTC: The first is to ensure that the stock status categorization is based on MSY benchmarks (or the 20 % B0 proxy), as indicated by the Kobe diagram (Fig. 2). The IOTC SC would need to decide if MSY can be robustly estimated for a given stock. If not, the proxy of 20 %B_0 would be used to characterize stock status and assign a color category as it is done in the WCPFC (see Table 2). For example, in the case of Indian Ocean skipjack, if the SC considers that MSY and its corresponding levels

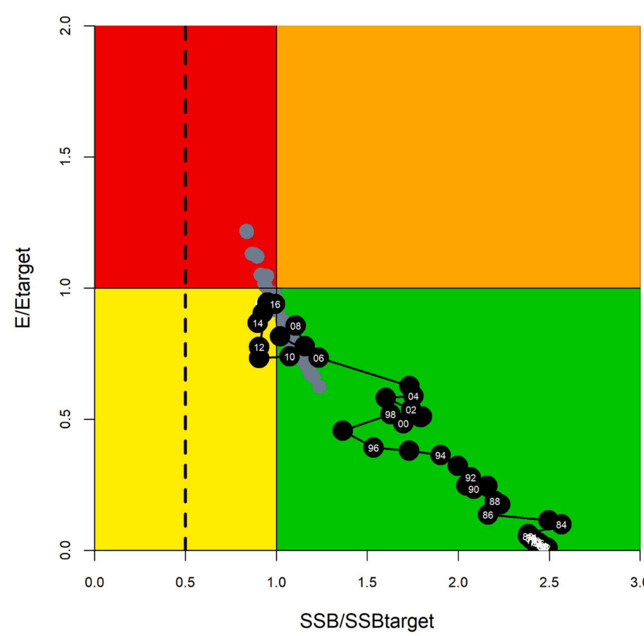

Fig. 5. Skipjack tuna: SS3 Aggregated Indian Ocean assessment plot of the 2017 uncertainty grid. Black circles indicate the trajectory of the median estimates for the SB/SB_{TRP} ratio and E/E_{TRP} ratio across all models of the 2017 uncertainty grid for each year 1950–2016; grey dots are the estimates for year 2016 from individual models. Extracted from the IOTC's Scientific Committee report (IOTC, 2017, IOTC–2017–SC20–R[E]). The green quadrant represents *"Not overfished and not subject to overfishing"*; orange represents *"Not overfished but subject to overfishing"*; yellow represents *"Overfished but not subject to overfishing"*; and red represents *"Overfished and subject to overfishing"*. The dashed vertical line represents the limit reference point adopted for this stock (20 % of virgin or initial spawning stock biomass SSB_0).

of biomass cannot be robustly estimated, the stock status category and associated probabilities would be determined using the proxy of 20 % of B_0 instead of the currently used 40 %B_0.

The second would be to adopt management objectives that aim to keep the stock in the green quadrant of the Kobe diagram with high probability, as it is done for Indian Ocean bigeye (Resolution 22/03) and swordfish (Resolution 24/08), where the management objective is to maintain the stock in the green quadrant with 60 % probability (or more) and the adopted MPs have been simulation-tested to achieve this [25,26]. This is a typical objective of fisheries management based on stock assessments and will implicitly combine the objective of maximizing stocks' productivity with reasonable levels of precaution. Another possibility would be to adopt biological TRPs at levels above B_{MSY} (or 20 % B_0) with maximum fishing mortalities limited to values lower than F_{MSY} (as done in the WCPFC). Biomass at or above the TRP would be achieved on average (~50 %) and therefore, the stocks would on average achieve biomass levels beyond those that can produce the MSY and, therefore, would be aligned with international legal frameworks for global fisheries. For skipjack, simulations show that biomass would meet the TRP with 50 % probability and stay above the LRP with 100 % probability with the recently adopted MP. These simulations also show that skipjack would remain in the green quadrant of the Kobe plot with 90 % probability [27]. In all cases, the characterization of stock status would be based on MSY benchmarks or 20 % B_0.

6. Final remarks

Color can play an important role in conveying information, modulating perceptions and influencing the decisions [1]. Conservation assessments often use green to represent good conservation and red for poor conservation [28]. For example, the IUCN Red List of Threatened Species highlights global extinction risks with colors from green (Least Concern) to red (Critically Endangered). Though criteria differ for commercial fisheries [29], similar colors are used to represent the status of fish stocks. In this document, we show that the effective communication of fish stock status still requires a shared understanding of the colors and other components of the scientific advice.

This study outlines the scientific advice and management frameworks for fisheries, with an emphasis on the IOTC. It explains that fishery management principles must align with systems developed to represent tuna stock status. The move towards an MP-based management system seems appropriate, although certain components may require refinement to ensure that all stakeholders correctly understand both the foundations and principles involved, avoiding confusion for non-specialist observers. Different fisheries management organizations might use varying thresholds or color conventions to indicate stock status; however, it is crucial that all stakeholders involved fully comprehend the principles and stock status categories.

Misunderstandings of fishery principles and color codes can bias perceptions of stock status and management effectiveness globally [30]. Although Indian Ocean skipjack has been abundant recently, it has been considered overfished with some probability due to the benchmarks used to represent its relative biomass (Table 2). This stock is certified as sustainable by the Marine Stewardship Council (MSC), which assesses fishery management and sustainability [31]. Unjustified concerns about the sustainability of the stock may arise if the stock falls below 40 % B0 but remains above biomass levels for maximum yield (B_{MSY} or its proxy of 20 %B_0). Our proposed changes aim to improve communication about stock status to avoid this. We also emphasize that implementing management procedures for long-term sustainable fish stocks, as done by the IOTC and other tuna RFMOs [2], would help achieve UN Sustainable Development Goals.

Cover letter

With this study we aim to contribute to the common understanding of marine policy in the field of fisheries science and management and we consider that this discussion paper will be of interest to a broad audience with interest in the better management of fisheries in general and tunas in particular. We describe a general framework for scientific advice for fisheries management and the problems we find in the case of Indian Ocean skipjack. We also propose a way forward to improve the management framework for the IOTC and all fisheries in general.

CRediT authorship contribution statement

Agurtzane Urtizberea: Visualization, Writing – review & editing, Conceptualization. **Gorka Merino:** Formal analysis, Writing – original draft, Methodology, Conceptualization, Visualization. **Hilario Murua:** Conceptualization, Writing – review & editing, Methodology. **Giancarlo M. Correa:** Conceptualization, Writing – review & editing. **Haritz Arrizabalaga:** Writing – review & editing, Conceptualization. **Ane Laborda:** Writing – review & editing, Conceptualization. **Josu Santiago:** Resources, Conceptualization, Writing – review & editing, Funding acquisition. **María Jaume:** Visualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Microsoft's AI assistant COPILOT in order to improve the readability of the text, which we have re-edited after. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Declaration of Competing Interest

We (the authors) declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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Data availability

Data will be made available on request.

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