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Status of MP development for Indian Ocean skipjack tuna

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Report prepared by:
Charles T T Edwards

For any information regarding this report please contact the author at:

CESCAPE Consultancy Services
South Africa & New Zealand

Email: cescapecs@gmail.com
Telephone: +64-21-575879

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Project Objectives

Work on an updated Management Procedure for skipjack has been ongoing since 2019. The current phase of the work began in October 2023, and will continue for a period of one year, with the objective to: Develop a Management Procedure for Indian Ocean skipjack tuna, including specification of the data inputs, that has been fully tested using a Management Strategy Simulation framework.

Specific objectives are:

- Re-visit the possibility of using a model-based Management Procedure based on the updated CPUE indices to be presented at WPTT25;
- Propose a set of candidate Management Procedures to the TCMP (2024) for potential adoption by the Commission.

The current report provides a review of work to date, and proposed future directions, for discussion by the WPM.

Introduction

In 2016, the IOTC adopted Resolution 16/02 (IOTC, 2016), based on the work of Bentley and Adam (Adam & Bentley, 2013, Bentley & Adam, 2014b,a, 2015, 2016). This described a harvest control rule (HCR) to be used for setting a recommended exploitation rate for skipjack (SKJ), based on outputs from the stock assessment (Figure 1). This stock assessment is conducted in the same year that the HCR is implemented, and each associated catch recommendation is valid for the subsequent three year period. Using outputs from the 2017 assessment (Fu, 2017), the HCR was first implemented at the end of that year to give a recommended catch limit for 2018–2020 of 470 thousand tonnes (IOTC, 2017, SC, 2017). A second implementation of the HCR was conducted in 2020 (SC, 2020), based on an updated stock assessment by Fu (2020). This assessment used catch data up to and including 2019, and the outputs were used to calculate a recommended catch limit for 2021–2023 of 513 thousand tonnes (IOTC, 2021a). The stock assessment is being repeated in 2023 using data up to 2021 (with an initial draft by Fu, 2023), with the outputs intended to be used for setting a recommended catch limit for 2024–2026.

Resolution 16/02 also requested a review of the HCR. In 2018, the IOTC Working Party on Methods (WPM) noted that Resolution 16/02 does not describe a fully specified Management Procedure (MP), since the underlying data and assessment methodology are not defined (IOTC, 2018). Hence the WPM suggested that the review be conducted with the aim of developing an MP for SKJ. This proposal was noted by the SC in 2018 (SC, 2018) and provides motivation for the current work.

As a starting point for the review, the Resolution 16/02 HCR was subjected to simulation testing by Edwards (2020b). This work validated utility of the HCR for setting catches, provided that stock assessment estimates of the biomass are unbiased. Since then, work has been directed towards the development of an MP that is not reliant on the assessment, but rather is capable of deciding on management actions independently, and shown through simulation that it has a high chance of reaching management objectives. Progress reports documenting this work have been submitted to the WPM (Edwards, 2020a,b, 2021a, 2022c), the WPM Management Strategy Evaluation Task Force (WPM-MSETF; Edwards, 2022a, 2023b), and the Technical Committee on Management Procedures (TCMP; Edwards, 2021b, 2022b, 2023a). The current report provides a review of progress and suggests future directions for the work.

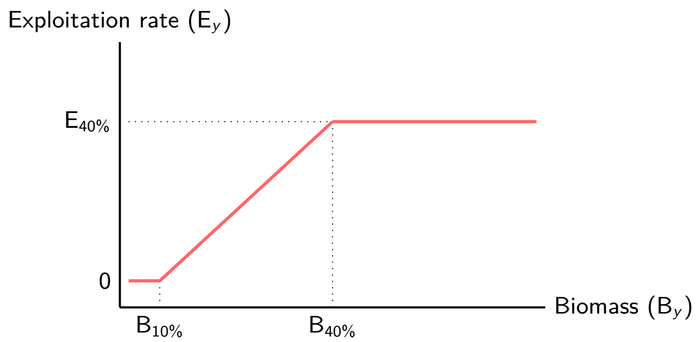

Figure 1: Schematic representation of the current Harvest Control Rule (Equation 1), which relates the estimated spawning stock biomass (B_y) to an exploitation rate (E_y).

Current management

The SKJ stock assessment predicts the spawning stock biomass (B_y) up to and including one year after the most recent year of catch data, and the HCR in Resolution 16/02 generates a recommended catch from this output. Using B_y, the HCR calculates an exploitation rate:

$$E_y = \begin{cases} E_{40\%} & \text{for } B_y \geq B_{40\%} \\ E_{40\%} \times \frac{B_y - B_{10\%}}{B_{40\%} - B_{10\%}} & \text{for } B_{10\%} < B_y < B_{40\%} \\ 0 & \text{for } B_y \leq B_{40\%} \end{cases} \tag{1a}$$

with the reference points ($E_{40\%}$, $B_{40\%}$ and $B_{10\%}$) treated as implicit tuning parameters (Figure 1). It then multiplies this exploitation rate by the spawning stock biomass to generate a recommended catch:

$$C_y^{TAC} = E_y \times B_y \tag{1b}$$

The following additional meta-rules were also endorsed:

- The recommended catch limit should not exceed 900,000 tonnes;
- The change in recommended catch from the previous year should not exceed 30% unless $B_y \leq B_{10\%}$, in which case C_y^{TAC} will always be zero.

Input values for the control rule ($B_{40\%}$, $B_{10\%}$, and $E_{40\%}$) are obtained as medians across estimated values from the grid of SS III assessment runs in the year in which the control rule is applied. For the assessment grid of Fu (2020), these are listed in Table 1.

Table 1: Median and 80% quantile status estimates across twenty-four model runs (Edwards, 2022b), estimated using SS3.30. Catch and biomass values are given in units of 1000 tonnes. This table is equivalent to the stock assessment results given in Table 3 of IOTC (2020). Values for 2020 are estimated assuming a one-year projection from 2019 with exploitation equal to $E_{40\%}$.

Quantity	Median (80% quantiles)
B_0	1984.605 (1744.839 - 2486.458)
$B_{40\%}$	793.842 (697.935 - 994.582)
B_{MSY}	477.103 (323.100 - 595.333)
B_{2020}	969.478 (706.899 - 1280.479)
$C_{40\%}$	532.075 (474.135 - 663.049)
C_{MSY}	605.834 (509.798 - 745.603)
C_{2020}	635.185 (483.536 - 790.993)
$E_{40\%}$	0.597 (0.541 - 0.650)
E_{MSY}	1.066 (0.795 - 1.501)
E_{2020}	0.580 (0.532 - 0.643)
B_{2020}/B_0	0.464 (0.389 - 0.518)
$B_{2020}/B_{40\%}$	1.161 (0.972 - 1.295)
B_{2020}/B_{MSY}	2.074 (1.516 - 2.72)
$C_{2020}/C_{40\%}$	1.140 (1.003 - 1.246)
C_{2020}/C_{MSY}	1.037 (0.900 - 1.116)
$E_{2020}/E_{40\%}$	0.980 (0.947 - 1.011)
E_{2020}/E_{MSY}	0.544 (0.418 - 0.681)

Development of the current HCR was based on an operating model (OM) that differed structurally from the current stock assessment. This can be problematic if the OM predicts profoundly different dynamics. Assuming that the SS III assessment model represents our best understanding of the resource, an OM that is, for example, more productive, may lead to an optimistic simulated outcome. This was investigated by Edwards (2020b), who showed that the HCR performed well when simulation tested using a SS III OM, and assuming that the biomass was "known" (i.e., input into the HCR without bias).

The current HCR requires an estimate of the stock status (B_y) and reference points ($B_{40\%}$, $B_{10\%}$, and $E_{40\%}$). These provide both the tuning parameters needed to define the control rule and the stock status inputs required to execute it. The use of median values is not a conservative approach (Edwards, 2020b), but use of B_y to set catches is conservative, because B_y is considered by the stock assessment model to be less than the total exploitable biomass. Nevertheless, reliance on updated stock assessment outputs each time the HCR is implemented means that the HCR itself is not fully specified. It will change over time. Although the stock assessment process may yield our best understanding of resource status, continuous refinement and development of the assessment model and data inputs mean that by it's nature it's performance cannot be simulated forward in time.

Development of a data-based Management Procedure

An MP, by definition, must be ameanable to simulation testing. This typically requires a parsimonious and well defined stock status estimator. To explore such a possibility, a biomass dynamic model was applied to catch and abundance data from the 2017 SKJ assessment, and shown to provide reasonable estimates of the depletion (Edwards, 2020a). However, since that initial work, the abundance indices have been updated (Medley et al., 2020b,a, Guery et al., 2020, Guery, 2020). Work presented to the WPM-MSETF in 2021 demonstrated that, given the updated indices, this type of model is no longer able to extract information on stock status (IOTC, 2021b). For this reason, an empirical or data-based MP was suggested as an alternative.

An empirical MP utilises a descriptive rather than process based model. Initial work towards development of this approach was presented to the TCMP by Edwards (2021b), with an MP that was based on standardised CPUE indices from the Maldivian PL and European PSLS fleets. These indices are both used routinely in SKJ assessments (Fu, 2017, 2020, 2023). The log-normalised transformation of these indices, averaged across all four seasons within the year, show similar trends over time (Figure 2), and there is a positive and linear relationship between the mean of the transformed indices (given notation a_y) and the stock biomass depletion (Figure 3). Edwards (2021b) showed that a_y can therefore be used as an informative input to an empirical MP, generating catches similar to those calculated assuming perfect knowledge of the resource biomass.

The proposed MP contained an HCR of the form:

$$C_y^{TAC} = \begin{cases} C_{max} & \text{for} \quad a_y \geq a_T \\ (C_{max} - C_{min}) \times \frac{a_y - a_X}{a_T - a_X} + C_{min} & \text{for} \quad a_X < a_y < a_T \\ C_{min} & \text{for} \quad a_y \leq a_X \end{cases} \tag{2}$$

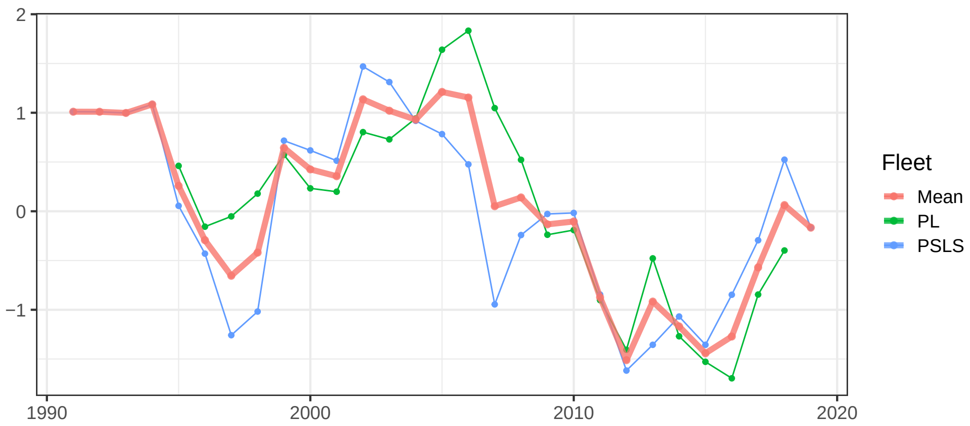

Figure 2: Time series of the log-normalised PL and PSLS indices (Fu, 2020).

For values $a_y \leq a_X$, the recommended catch is equal to C_{min}. As a_y increases, the recommended catch also increases, until for values of $a_y \geq a_T$ the recommended catch is equal to C_{max} (Figure 4). In this case the tuning parameters (a_X, a_T, C_{min} and C_{max}) are a fixed part of the MP, allowing simulation testing of it's performance with different tuning parameter values. Values for a_X and a_T were chosen that corresponded to the $B_{10\%}$ and $B_{40\%}$ tuning parameters in Equation 1, and C_{max} was adjusted around the $C_{40\%}$ value of 532 thousand tonnes (Table 1).

Tuning of the MP, through adjustment of the tuning parameters, has been described by Edwards (2021b,a), Edwards (2022a,b,c) and Edwards (2023b,a), focusing largely on the effect of changes in C_{max}. Within the IOTC, "tuning" is conducted with reference to pre-defined performance criteria, namely biomass status and the rate of exploitation, which define managment objectives for the stock (IOTC, 2015). Multiple parameterisations of an MP may yield similar outcomes, and equivalence on these two axes facilitates comparision between MPs using other performance metrics.

Following inital presentation of the work, the TCMP recommended that empirical MPs be tuned using the Kobe Green quadrant as a measure of stock status (IOTC, 2021d). Specifically, MPs were to be selected using the simulated probability of the stock being in the Kobe Green quadrant when averaged across projection years 11 to 15 (2030 to 2034 inclusive). Tuning criteria that matched a 50%, 60% and 70% probability of being in the Kobe Green quadrant were adopted. In common with other IOTC stocks, if an MP matched one of these criteria then it would be selected for further consideration. The Kobe Green quadrant is defined by the B_{MSY} and E_{MSY} reference points. Because of historic difficulties in estimating MSY for SKJ, these have been conventionaly set at $B_{40\%}$ and $E_{40\%}$ respectively (IOTC, 2015, 2016). Tuning was therefore initially caried out with reference to $B_{40\%}$ and $E_{40\%}$, and this was referred to as the "Kobe Green" quadrant. However, following presentation and discussions at the WPM-MSETF in 2023, it was decided that the tuning quadrant should be referred to as the "target" quadrant, but retaining its definition using $B_{40\%}$ and $E_{40\%}$ reference points (Edwards, 2023b, IOTC, 2023a). This was a change in terminology only, but it importantly allowed diagnostics to be presented relative to both $B_{40\%}$ and $E_{40\%}$, and B_{MSY} and E_{MSY}. At the TCMP in 2023, revised Kobe plots (Figure 5) and an updated table of diagnostics (Table 2) were presented (Edwards, 2023a). These results represent the lastest iteration of the work.

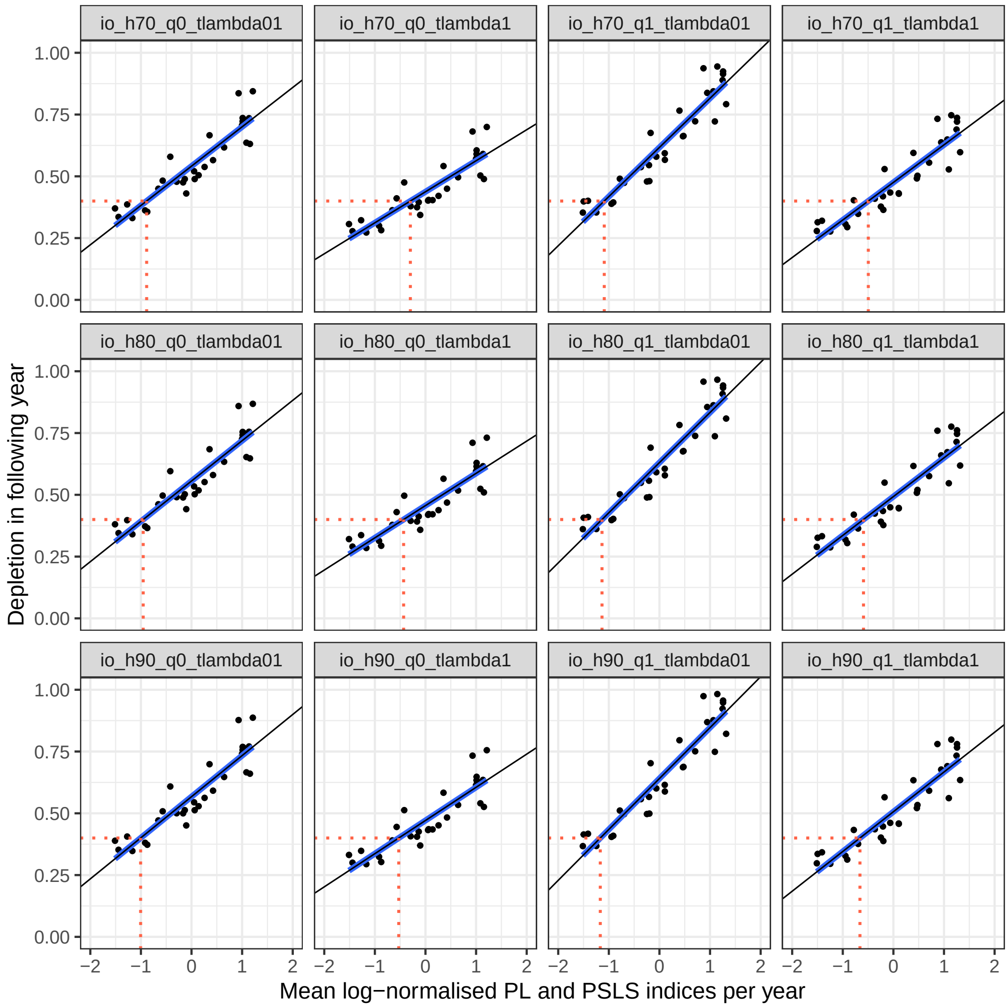

Figure 3: Relationship between mean log-normalised PL and PSLS indices (a_y) and biomass depletion estimated by the twelve single-area stock assessment model runs of Fu (2020) and IOTC (2020).

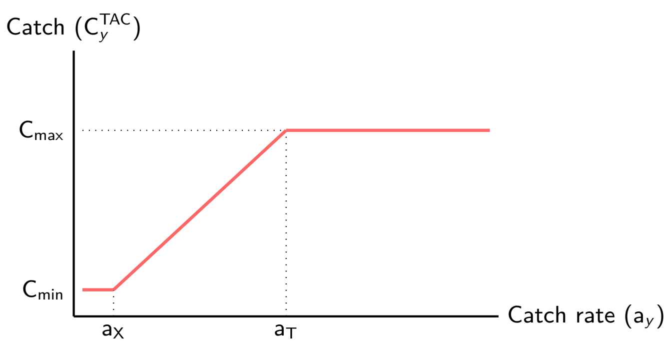

Figure 4: Schematic representation of the empirical Harvest Control Rule (Equation 2) that was proposed as part of a data-based MP (Edwards, 2021b,a).

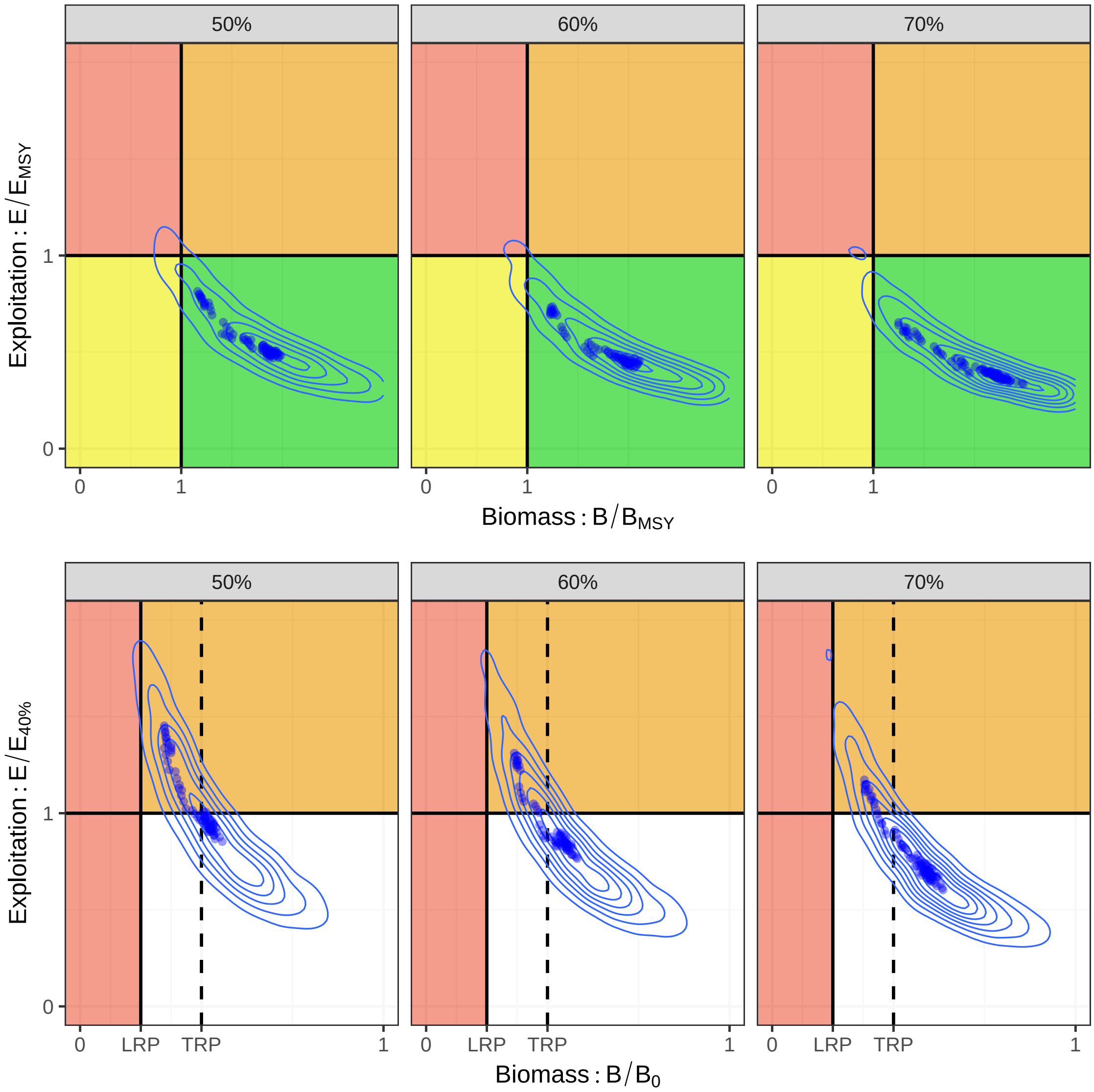

Figure 5: Kobe phase plots (top panel) and Majuro phase plots (bottom panel) for tuned MPs listed by Edwards (2023a). Contours show a two-dimensional histogram of stock status across all years for which the MP was used to set catches (i.e. 2024 to 2040), twenty-four model runs and ten stochastic iterations for each run. Blue points show the median values per year and MP for each tuning criteria. The Kobe and Majuro matrices differ in the reference points used to diagnose stock status. The Kobe matrix is defined using MSY-based reference points B_{MSY} and E_{MSY}, whereas the Majuro plot uses Target and Limit Reference Points (TRP and LRP) equal to $B_{40\%}$ and $B_{20\%}$ respectively. Estimates for $B_{40\%}$, $B_{20\%}$ and B_{MSY}, and associated exploitation rates, were obtained from the stock assessment and are listed in Table 1.

Table 2: Diagnostic outputs for MP evaluations over 17 year projection period (2024 to 2040). Each performance statistic is generated by first calculating the summary statistic per run and iteration across projection years, and then reporting the median and 80% quantiles across those values – unless the statistic is a probability, in which case it is calculated as a proportion across all projection years, runs and iterations simultaneously. For catch stability statistics, only six TAC implementation years (from 2024 inclusive) were used, and were calculated relative to the previous TAC.

Performance Statistic	Description	Summary statistic
Catch		
C_y^{TAC}	Total Allowable Catch (three years)	Mean
C	Total realised catch	Mean
$C_{[PL]}$	Catch for PL fleet	Mean
$C_{[PSLS]}$	Catch for PSLS fleet	Mean
$C_{[PSFS]}$	Catch for PSFS fleet	Mean
$C_y/C_{40\%}$	Catch rel. to target	Geometric mean
C_y/C_{MSY}	Catch rel. to MSY	Geometric mean
Catch stability (TAC years only)		
$C_y^{TAC} \neq C_{y-1}^{TAC}$	n. TAC changes	Count
$\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	TAC change	Mean % change
Max. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert$	Max. TAC change	Max. % change
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 10\%$	TAC change $> 10\%$	Probability
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert > 5\%$	TAC change $> 5\%$	Probability
Pr. $\lvert C_y^{TAC}/C_{y-1}^{TAC} - 1\rvert = 15\%$	TAC change at limit	Probability
Catch rate		
$CPUE_{[PL]}$	CPUE for PL fleet	Geometric mean
$CPUE_{[PSLS]}$	CPUE for PSLS fleet	Geometric mean
Exploitation rate		
E_y	Exploitation rate	Geometric mean
$E_y/E_{40\%}$	Exploitation rel. to target	Geometric mean
E_y/E_{MSY}	Exploitation rel. to MSY	Geometric mean
Stock biomass		
B_y	Stock biomass	Mean
B_y/B_0	Depletion rel. to B_0	Geometric mean
B_y/B_{MSY}	Depletion rel. to B_{MSY}	Geometric mean
B_{MIN}/B_0	Min. depletion	Minimum
Pr. $> B_{20\%}$	$B_y > B_{20\%}$	Probability
Pr. $> B_{10\%}$	$B_y > B_{10\%}$	Probability
Target Quadrant		
Pr. Target Quadrant	$B_y > B_{40\%}$ and $E_y < E_{40\%}$	Probability
Kobe Quadrants		
Pr. Kobe Red	$B_y < B_{MSY}$ and $E_y > E_{MSY}$	Probability
Pr. Kobe Green	$B_y > B_{MSY}$ and $E_y < E_{MSY}$	Probability
Majuro Quadrants		
Pr. Majuro Red	$B_y < B_{20\%}$	Probability
Pr. Majuro White	$B_y > B_{20\%}$ and $E_y < E_{40\%}$	Probability

Robustness testing

Based on feedback from the WPM in 2021 (Edwards, 2021a, IOTC, 2021c), Edwards (2022a) subsequently presented robustness testing results to the WPM-MSETF in 2022. The robustness testing considered overcatch error (i.e. catches higher than the recommendation) and the potential consequences of recruitment failure. Overcatch is a persistent concern (Table 3) that needs to be addressed either at the governence level, or through temperance of the scientific advice (i.e., reduction in the recommended catch). Recruitment failure is a concern because of suspected correlations between SKJ recruitment and environmental conditions in the Indian Ocean (Marsac, 2023a,b), which may become unfavourable in the future.

Based on this work, a preliminary set of candidate MPs was presented to the TCMP in 2022, and received feedback (Edwards, 2022b, IOTC, 2022b). In particular the TCMP requested to include overcatch error as part of the tuning process. In response to this request, candidate MPs were tuned to the 50%, 60% and 70% turning criteria under the assumption of constant overcatch error values of 10%, 20%, 30% and 40%. These results were presented to the following WPM (Edwards, 2022c, IOTC, 2022a) and then subjected to further robustness testing for presentation to the WPM-MSETF (Edwards, 2023b). However, at that meeting it was recommended that tuning of the MPs should not include overcatch error (IOTC, 2023a). Candidate MPs finally presented at the TCMP in 2023 therefore did not include overcatch as part of the tuning process (Edwards, 2023a), but rather tested performance of tuned MPs to externalised overcatch (i.e., overcatch that is not accounted for in the recommendations produced by the MP but treated as a cost in terms of poor MP performance).

Testing results have demonstrated that the MP is predicatably sensitive to recruitment failure, with severity of the effect dependent on the timing relative to the three year period over which the recommended catch is fixed (Edwards, 2023b). Failure at the beginning of the period has the most servere consequences, but in all cases the MP behaved predictably, and was able to recover the stock if it had not been driven to extinction before the fist year of MP implementation. Robustness testing of overcatch error was similarly intuitive (Edwards, 2023a), indicating that MP performance deteriorates at higher overcatch levels and providing an argument in favour of more conservative MPs (i.e., tuned to the 70% target quadrant).

Table 3: Recommended catch from Resolution 16/02 and realised catches reported by IOTC (2023c) in tonnes.

Year	Recommended catch	Realised catch
2018	470,029	606,133
2019	470,029	590,390
2020	470,029	547,258
2021	513,572	655,115
2022	513,572	–
2023	513,572	–

Further work

An empirical MP has a number of advantages, including its simplicity, which makes it easier to simulation test and interpret. Nor is an empirical MP necessarily inferior to model-based approaches (Geromont & Butterworth, 2015). However, within the IOTC, an empirical MP would be the exception. A model-based MP was recently adopted for Bigeye and similar MPs are at the forefront of development work for albacore and swordfish. Despite the apparently reasonable performance of the empirical MPs that have so far been tested for SKJ, the TCMP in 2023 (IOTC, 2023b) has requested that a model-based approach be revisited:

35. The TCMP NOTED that when the project began in early 2019, a model-based MP utilizing a biomass dynamic model (BDM) was initially considered and performed well. However, the BDM did poorly when the CPUE was later updated and revised (mostly because the contrast between catch and CPUE, which is the signal needed for a biomass dynamic model, is lacking). As a result, the current work is focusing on the data-based MP. The TCMP NOTED that a new CPUE index will be produced this year and requested the developer to investigate the viability and effectiveness of any potential model-based MP based on the new CPUE as is done with several other MSEs in IOTC.

These new abundance indices have recently been made available by Medley et al. (2023) and Kaplan et al. (2023). The TCMP further questioned the use of an HCR with a constant catch at high stock biomass levels (Equation 2):

34. The TCMP NOTED that the TAC output of the MP is bounded between *Cmin* and *Cmax*. This indicates that when the stock is healthy catches will be restricted; and when the stock is depleted catches will be permitted (through a minimum). However, it was noted that maintaining a constant catch when the biomass is below the limit will increase fishing mortality rather than decrease it, which seems contrary to what should be done. The TCMP discussed whether exploitation rate as an output might be preferred. However, converting the exploitation rate to catch would require abundance estimates from an external assessment, or a biomass dynamic model which often calculates abundance less accurately than depletion and therefore would introduce additional uncertainty.

Compared to Figure 1, the relationship in Figure 4 is theoretically inferior because catch will be limited at high stock biomass values and remain positive even when it drops below a_X (the index value at approximately $B_{10\%}$). However, it is practically more defensible because it removes the need for multiplication by an unknown stock biomass in order to generate the catch (Equation 1b). Furthermore, in choosing a suitable value for C_{max} it can make use of an arguably axiomatic feature of fisheries management, namely that if the stock has not gone extinct then the sustainable catch has not yet been exceeded. Notwithstanding changing catch selectivities or environmental conditions, an HCR that limits the catch to a maximum value less than the historic maximum is making use of the full exploitation history of the stock to ensure a high chance of sustainability into the future.

If the new CPUE indices available this year (Medley et al., 2023, Kaplan et al., 2023) still preclude application of a biomass dynamic model, and if a model-based MP is still considered intuitively more desireable than an empirical approach, then this will require the use of non-standard models of the biomass dynamics. Fundamentally however, if information is not being provided by the CPUE and catch time series, then a new source of data is required, with the model built around that data. One source of information that is potentially under-utilised, even by the SS III stock assessment (Maunder & Hoyle, 2023), is the tagging data from the Indian Ocean regional tuna tagging program (RTTP-IO), which seeded a large number of tags into the SKJ population in the mid-2000's. Models exist that have attempted to extract abundance or fishing mortality directly from these data (Polacheck et al., 2006, Hillary, 2008, Eveson, 2011). This information could potentially be used to "anchor" a simple model of the biomass dynamics, creating a catch-driven model similar to that proposed by Zhou et al. (2017). Depending on feedback from the WPM, the opportunity exists for exploration of this approach.

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