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Options for Multispecies Catch Limits in Harvest Strategies for Indian Ocean Tropical Tunas

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Abstract

The Sustainable Indian Ocean Tuna Initiative (SIOTI) is a large-scale Fisheries Improvement Project (FIP) comprising the major purse seine fleets and tuna processors in the region. As part of the activities of the FIP, we have explored options for harvest strategies that account for the technical interactions between the three tropical tuna stocks exploited in the Indian Ocean. For this, we have reviewed the different steps and components of the Management Strategy Evaluation (MSE) process that will need to be developed. As a start of this process, we have developed different multispecies management objectives, we have conditioned a preliminary multispecies operating model and we demonstrate the utility of multispecies management procedures.

1. Introduction

In recent years the IOTC has made significant advances in developing MSE frameworks for tropical tuna species to evaluate harvest strategies (Kolody and Jumppanen 2019; Kolody and Jumppanen 2019; Edwards 2021; Hillary, Williams et al. 2021). However, these MSEs cannot anticipate the unintended consequences of single stock management frameworks on the other tropical tunas and/or fleet responses to management measures.

The aim of this study is to explore the potential for adoption of multispecies catch limits as a harvest strategy for tropical tunas in the Indian Ocean.

In this work we present a preliminary MSE framework to evaluate multispecies management objectives, conditioned multi-species OMs for Indian Ocean tropical tuna stocks and fleets to demonstrate the utility of multi-species Management Procedures.

3. Methods

a. Multi-species Operating Model Conditioning

In this section we present a preliminary configuration of a multispecies Operating Model (OM) for the tropical tuna fisheries. For this, we explain the modelling tool FLBEIA (Garcia, Prellezo et al. 2012; Garcia, Sánchez et al. 2017) and how the most recent assessments of the three stocks have been used to condition the numerical framework and the necessary modifications for conditioning the multispecies OM.

The most recent assessments of Indian Ocean bigeye, skipjack and yellowfin were carried out in 2019, 2020 and 2021 respectively, using the integrated stock assessment software Stock Synthesis (Methot Jr and Wetzel 2013; Fu 2019; Fu 2020; Fu, Urtizberea et al. 2021). The OM will simulate the dynamics of the tropical tuna fishery system. The interaction between the biological population and the fleets will be performed through fishing effort, selectivity, and catch.

The model

The modelling platform FLBEIA, includes a bio-economic impact assessment model based on the MSE approach (Garcia, Urtizberea et al. 2013; García, Prellezo et al.

2017). This model is written in R and requires the use of FLR libraries (www.flr-project.org). FLR provides the basic pieces to construct the model and FLBEIA assembles them to build a composable framework. FLBEIA has been applied to several case studies with scientific and/or management objectives. While most of the MSE examples are single stock, FLBEIA has been used in several multi-stock and multi-fleet case studies. (STECF 2015; Garcia, Prellezo et al. 2016; Prellezo, Carmona et al. 2016,González-Costas, Miller et al. 2014).

Operating Models for Indian Ocean bigeye, yellowfin and skipjack tuna

The population variables and, biological and other fishery parameters for the multispecies OM were directly extracted from the output files of the Stock Synthesis models. These include the numbers at age, the vectors of weight at age, maturity, natural mortality, stock-recruitment relationship, and the selectivity of fisheries. Further details on the biological characteristics, parameters and can be found in the stock assessment documents of the three stocks (Fu 2019; Fu 2020; Fu, Urtizberea et al. 2021).

Temporal Stratification

The three stock assessments were developed for different temporal periods, and it is key to homogenise this for the multispecific framework:

- The bigeye stock assessment model commenced in 1975 and assumed an exploited, equilibrium initial state. The period of the bigeye assessment was from 1975 to 2018. The time period covered by the yellowfin assessment is 1950–2020 representing the period for which catch data are available from the commercial fishing fleets, and the model assumed an initial unfished equilibrium state in 1950. The skipjack population was also assumed to be in an unfished equilibrium in 1950 at the start of the catch data series and the model was developed from 1950 to 2019.
- Within the models of bigeye and yellowfin, the annual data were compiled into quarters (Jan–Mar, Apr–Jun, Jul–Sep, Oct–Dec), and the models were built using a quarterly time step which is treated as a model year. The time steps were used to define model “years” (of 3-month duration) enabling recruitment to be estimated for each quarter to approximate the continuous recruitment of bigeye, for yellowfin in the equatorial regions. For skipjack,

the model considers years and seasons, and estimates spawning stock biomass (SSB) once every year for estimating annual recruits from a stock recruitment relationship.

Spatial Stratification

The spatial configuration of the three stock assessments is different and also, it is key to homogenise them for the multispecific framework:

In the assessment of Indian Ocean bigeye in 2019, the spatial domain of the was stratified into four regions: western equatorial region (Region 1), partitioned at the equator into Region 1S and Region 1N, in order to account for differences in the distribution of tags within this region; eastern equatorial region (Region 2) and southern region (Region 3) (Figure 1) (Fu 2019).

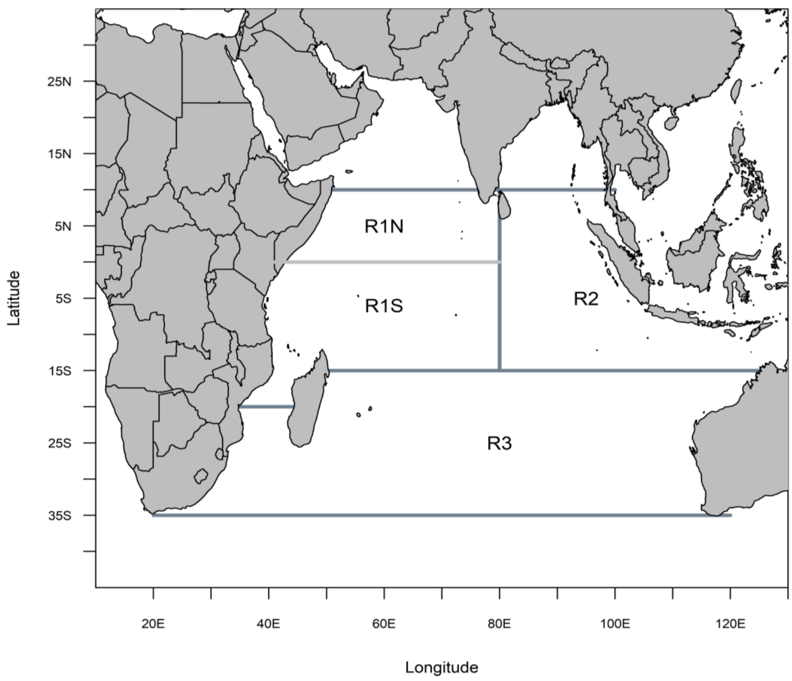

Figure 1. Spatial stratification of the Indian Ocean for the BET four-region assessment model (Fu 2019).

In the 2021 yellowfin assessment a four-region model structure was adopted (Figure 2), combining the Arabian Sea (region 1a) and western equatorial regions (region 1b), although the two sub regions were retained for the definition of spatially distinct fisheries that operate in each area. The spatial structure retains two regions that encompass the main year-round fisheries in the tropical area and two austral, subtropical regions where the longline fisheries occur more seasonally (Fu, Urtizberea et al. 2021).

In the 2020 skipjack assessment it was assumed that there are two distinct populations (west and east of 80°) (Figure 3). This partition is based on the distribution of major fisheries and appears well fitted with geographical scale of the observed skipjack movements in the western Indian Ocean (Fu 2020).

A first step in conditioning the multispecies OM was to harmonize the spatial distribution of each model with the geographical distribution of the activity of fleets.

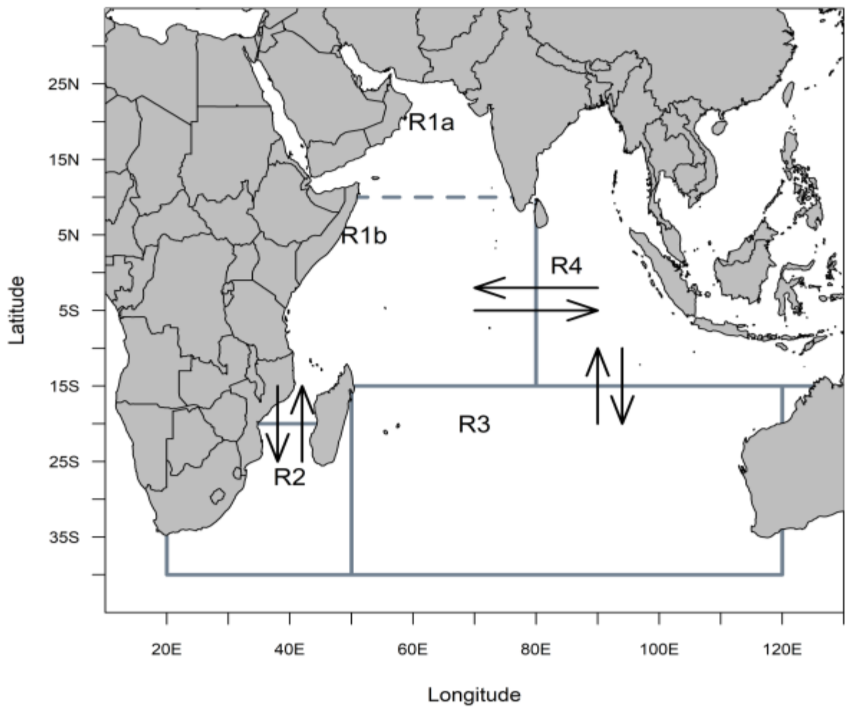

Figure 2. Four region spatial stratification of the Indian Ocean for the YFT. The black arrows represent the configuration of the movement parameterisation of the assessment model (Fu, Urtizberea et al. 2021).

For this, the fleet structure considered in the three stock assessment models was reviewed.

Fleet structure

- The 2019 bigeye assessment (Fu 2019) defines fifteen fisheries based on the fishing gear type and the regional stratification. The longline fishery was split into two main components based on vessel types (industrial or artisanal). The Purse seine fishery was also partitioned by the fishing mode (set type) (FAD associated and free school). In the case of the yellowfin assessment (Fu, Urtizberea et al. 2021), twenty-one fisheries were defined based on location (region), time period, fishing gear, purse seine set type, and type of vessel in the case of longline fleet. For skipjack, the stock assessment considered seven fleets on the basis of the gear type and fleet of operation.

These "fisheries" represent relatively homogeneous fishing units, with similar selectivity and catchability that do not vary greatly over time.

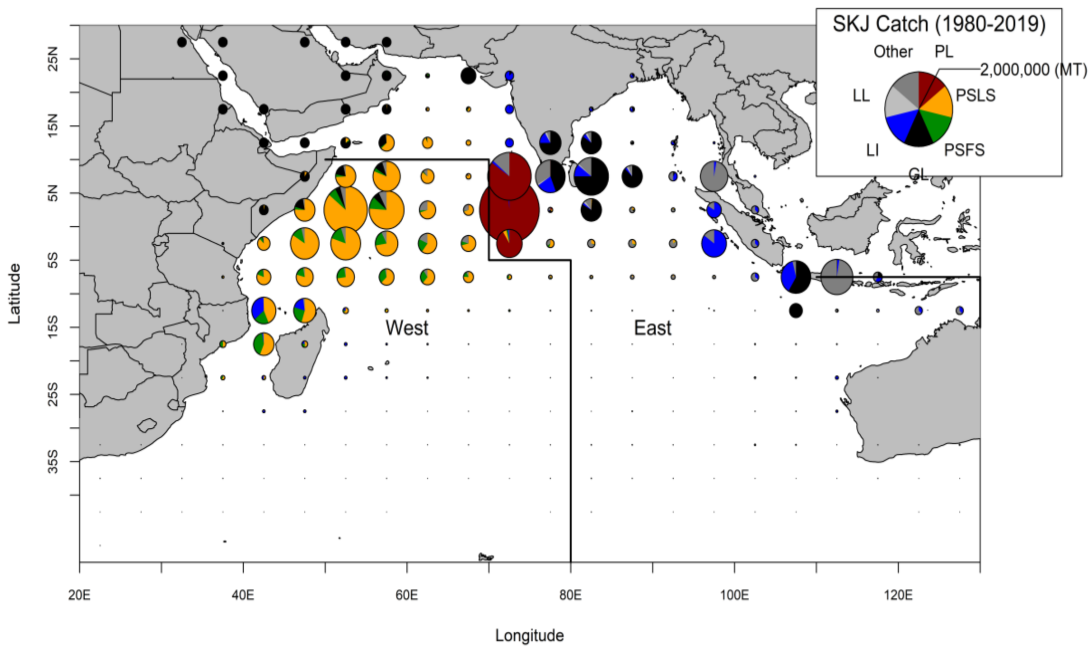

Figure 3. Spatial distribution of Indian Ocean skipjack catches by main fisheries aggregated for1980-2019. Areas used in two-area spatial structure model (Fu 2020).

Multi-species assessment model

- *Temporal stratification:* In order to combine the three species in a multi-species assessment model, the temporal stratification of bigeye and yellowfin was transformed to match the internal year-season structure of the skipjack assessment. Also, the time span of the three assessments was reduced to 1950 – 2018.

- *Spatial stratification:* A new spatial stratification was designed for the multi species model (Table 1). This new design is based in a 3-region model, in which the individual areas of each species were combined as follows: the new "Area 1" is a combination of bigeye 1N and 1S regions, yellowfin 1b region and skipjack west region; "Area 2" combines bigeye Region 2, yellowfin 1a and Region 4 and East region of the skipjack stock assessment; "Area 3" combines bigeye Region 3 with yellowfin areas R3 and R2.

Table 1. New spatial stratification design

	Área 1	Área 2	Área 3
BET	1N + 1S	R2	R3
YFT	1b	1a + R4	R3 + R2
SKJ	West	East	

- *Fleet structure:* Based in the new spatial structure, the fleets were also redefined as shown in Table 2. Two different fleets that were defined as 'Others' in the assessments have been redefined as TRO1 and TRO2. Both catch bigeye and yellowfin, and represent artisanal fisheries (e.g., gillnet, trolling and a range of small gears.). The model assumes that the three stocks are fished simultaneously which was necessary to adapt the individual fleets from the assessments into the multispecies MSE. It would be advisable to adapt the stock assessments of the three tropical tuna stocks to a common fleet structure to facilitate the multispecies MSE.

Technical interactions

The key aspect of the multispecies MSE is the definition of the technical interactions between the three stocks. In our framework we do this by using scalars of fishing effort allocation, as defined by García et al (2013): *Effort allocation determines how much effort is exerted* (to obtain catch) *and how this is allocated among metiers within a fleet.* Catch production describes the relationship between effort and catch.

Table 2. New fleets structure for each species: bigeye, yellowfin and skipjack.

BET		YFT		SKJ	
Assessment Fleets	New Fleets	Assessment Fleets	New Fleets	Assessment Fleets	New Fleets
LL1N + LL1S	LL1	LL1b	LL1		
PSFS1N + PSFS1S	PSFS1	PSFS 1b	PSFS1	PSFS	PSFS1
PSLS1N + PSLS1S	PSLS1	PSLS 1b	PSLS1	PSLS	PSLS1
BB1	BB1	BB1b	BB1		
OT1	TRO1*	TR 1b	TRO1		
				Gillnet	GI1
FL2	FLL2	LF 4	FLL2		
LL2	LL2	LL 1a + LL 4	LL2	Longline	LL2
PSFS2	PSFS2	PSFS 4	PSFS2		
PSLS2	PSLS2	PSLS 4	PSLS2		
LINE2	HD2	HD 1a	HD2	LINE2	HD2
OT2	TRO2*	TR 4	TRO2		
		OT 1a + OT 4	OT2		
		GI 1a + GI 4	GI2		
				Other	PSOT2
				PL	PL2
LL3	LL3	LL 2 + LL 3	LL3		
		PSFS 2	PSFS3		
		PSLS 2	PSLS3		
		TR 2	TRO3		

b. Management Procedure

The management procedure assumed perfect observation in order to draw the data from the Operating Model without any error sources.

The simulation is based on the definition of a multi-stock catch-based HCR (Garcia, Prellezo et al. 2016), whose objective is to avoid underreporting and discards and to maximize the overall catch while ensuring the sustainability of the stocks.

A multi-species HCR should fulfill the following properties:

1. Produce compatible catch advice among the stocks.
2. Take the most out of fishing opportunities (catch).
3. Result in fishing mortality levels compatible with the MSY ranges, for example from the PGY approach (Hilborn 2010).

The effort model used was a Simple Mixed Fisheries Behaviour (SMFB) model, which describes the dynamics of a fleet working in a mixed-fisheries context. In this model, only the total effort is calculated as the effort share along metiers is given as an input. First the effort corresponding to the quota-share of each stock is calculated, this returns one effort per stock caught by the fleet. Then different options are available to select the effort to be exerted by the fleet based on the efforts corresponding to the quota-shares (minimum, maximum, mean, previous, the most similar to the previous year effort, and stock-name, the effort corresponding to the stock specified). This approach is based on the *Fcube* method (Iriondo, García et al. 2012).

The simulation framework is based on the *FCube* methodology and a range of potential multispecific scenarios. The model uses the output of the single stock assessments and evaluates the consequences of different management options (e.g. catch limits for each stock and/or effort allocations by fleet). *FCube* produces catch advice for multiple stocks following a series of rules or scenarios, including multispecies Harvest Control Rules (HCR).

In the examples developed for this document, the management advice is generated following the ICES MSY framework (ICES HCR) (Figure 4), which can be found in the WKFRAME report (ICES 2012). This HCR's objective is to maintain the fishing mortality at FMSY. The corresponding fishing mortality is transformed into catch in order to obtain the TAC advice. For each stock, the model estimated reference points and control variables for the HCR (Table 3).

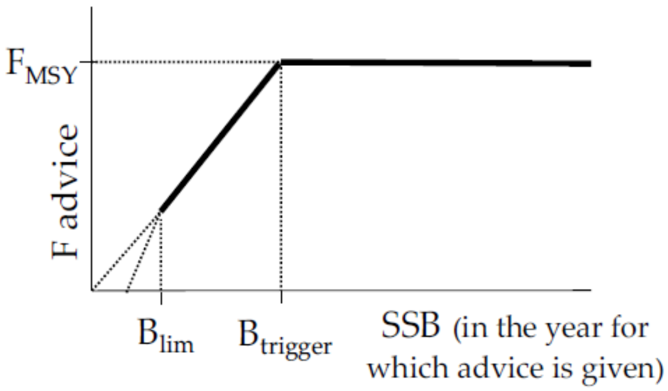

Figure 4. Graphical representation of HCR corresponding to ICES MSY framework, adapted from WKFRAME report ICES (2010).

Table. 3. Reference points for the HCRs for yellowfin, bigeye and skipjack.

Reference Points	BET	YFT	SKJ
Blim	53257.2	122819	39055.4
Btrigger	213028.8	491276	156221.6
F_{MSY}	0.256	0.168	0.6

Apart from these, different fixed advice scenarios were simulated, in which the effort was reduced by 10% (Effort 90) and by 30% (Effort 70) for all fleets; and a mixed scenario in which the log set purse seiners fleets' effort was reduced by 20% and the free-school purse seiners, baitboats, gillnets and trolling fleets' efforts were reduced by 10% (Effort Mixed).

The MP was composed by two types of HCRs: 1) A fixed advice of constant TAC based on effort, 2) A multi-stock HCR aiming at MSY ranges for the three tropical tuna stocks (Table 4).

Table. 4. Harvest Crontol Rules tested for mixed fisheries.

HCRs		Explanation
Fixed Advice	EF90	Reduction of 10% of all fleets' effort
Fixed Advice	EF70	Reduction of 30% of all fleets' effort
Fixed Advice	EFMix	Reduction of 20% of PSLS and 10% reduction in PSFS, BB, GI and TRO
Multistock	SMFB max	The fleet will continue fishing until the catch quotas of all the stocks are exhausted
Multistock	SMFB min	The fleet will stop fishing when the catch quota of any of the stocks is exhausted.
Multistock	SMFB YFT	For each fleet, fishing stops when an average achievement of all catch limits meets the YFT fleet's stock share.

4. Results

Before analysing the results obtained with the HCRs, it needs to be noted that this is a preliminary work and it is focused on showing how the interaction between the 3 species of tropical tunas work in the Indian ocean.

The following figures show the historical data regarding the catch, fishing mortality, recruitment, and estimated spawning biomass for each species, as well as the projection data for each scenario simulated. In these figures, we show how each stock responds differently and/or in different intensities to the scenarios simulated.

For example, in the 'Effort Mixed' (EFMix) scenario, we reduced the PSLS fleets' effort by a 20%. As these are the main fleets capturing SKJ (almost 31% of the total catch) but are not that important for YFT and BET (15% and 10%, respectively), the stocks' response can vary.

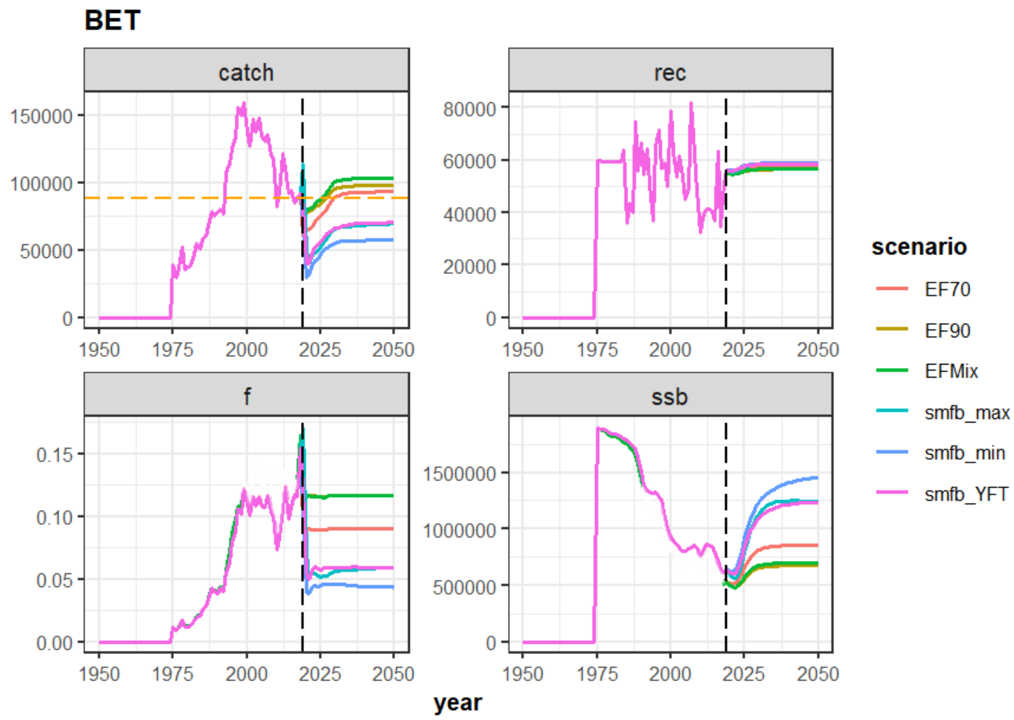

Figure 4. Historical and estimated median values of bigeye catch, recruitment, fishing mortality (f) and spawning stock biomass (ssb), as estimated by 5 HCRs (scenarios).

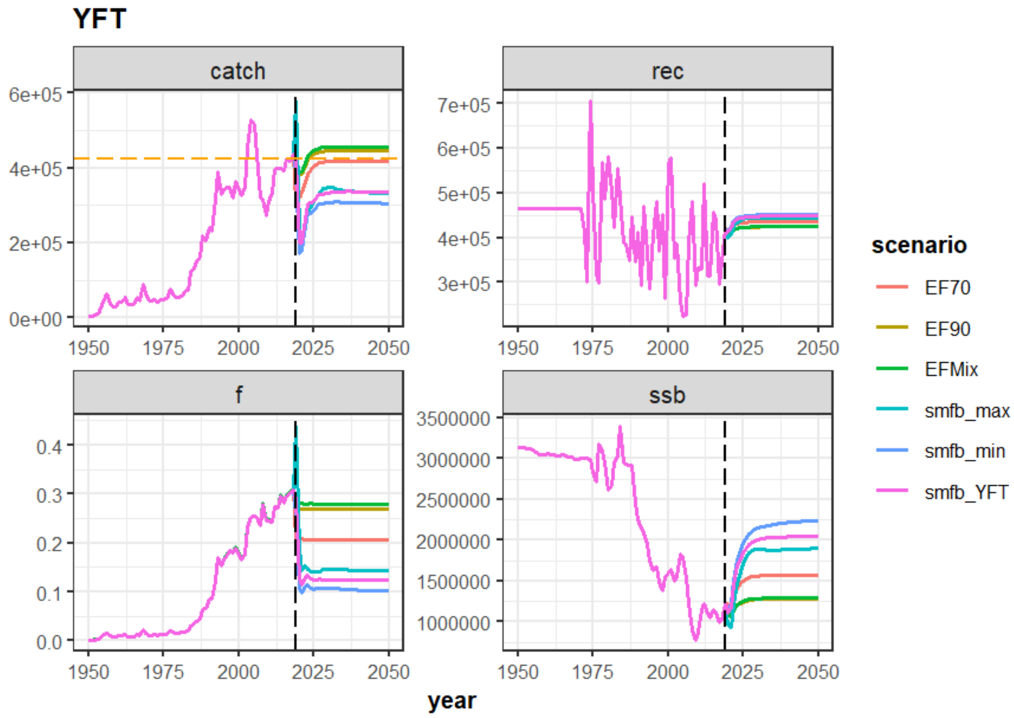

Figure 5. Historical and estimated median values of yellowfin catch, recruitment, fishing mortality (f) and spawning stock biomass (ssb), as estimated by 5 HCRs (scenarios).

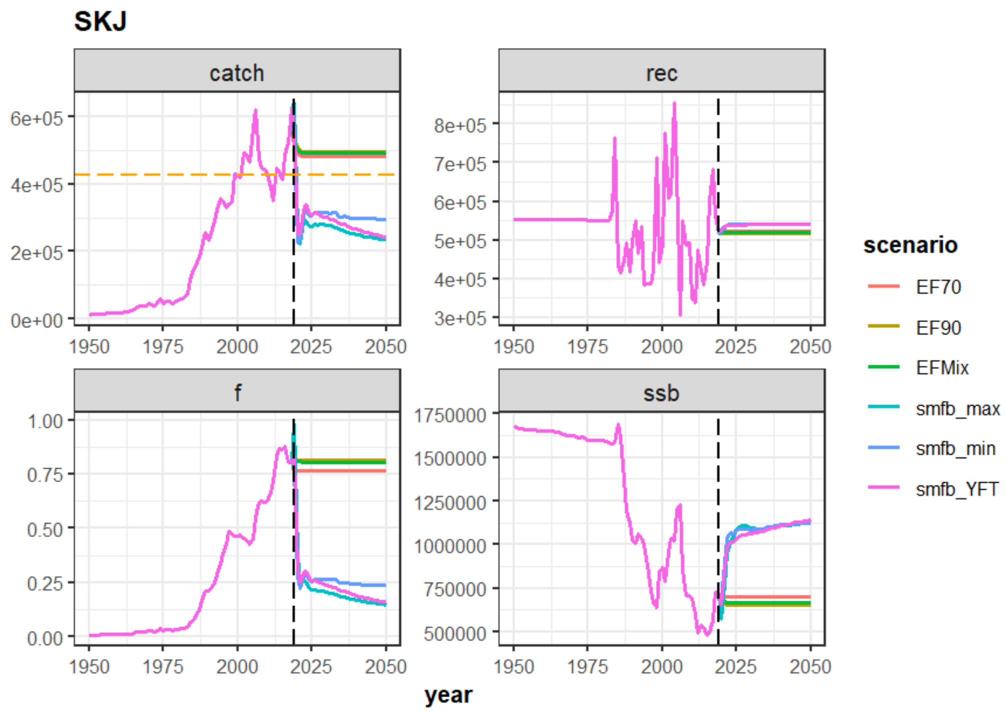

Figure 6. Historical and estimated median values of skipjack catch, recruitment, fishing mortality (f) and spawning stock biomass (ssb), as estimated by 5 HCRs (scenarios).

5. Discussion

In this paper we present a preliminary configuration of a multispecies Operating Model (OM) for the tropical tuna fisheries. Apart from this, we also simulate several HCRs as a prototype of the multispecies MSE work that is already being done in a similar way in the Atlantic and in the WCPFC (WCPFC-SC17-2021).

In this study, we present HCR options developed before for mixed fisheries in the International Council for the Exploration of the Seas (ICES), aiming to help identify the multispecies Management Procedures that could achieve different multispecies objectives.

As a following step, management objectives that address the multispecies nature of tropical tunas need to be developed. For doing so, the technical interactions among the fleets should be further investigated in order to develop adequate harvest strategies for each stock.

6. Acknowledgements

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