Stock Assessment of Indian Ocean Indo-Pacific king mackerel (*Scomberomorus guttatus*) using CMSY data poor method

Seyed Ahmadreza Hashemi[1], Farhad Kaymaram[2], Ali Salarpouri [3], Mastooreh Doustdar[2]

[1]Offshore Fisheries Research Center, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization

[2]Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization

[3] Persian Gulf and Oman Sea Ecological Research Center, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization

Abstract

The purpose of this study was to develop a framework for investigating the catch trend. However, it is currently difficult to provide scientific advice for management purposes using only catch data. This article presents a data poor method for stock assessment of *Scomberomorus guttatus* by collecting catch data in the Persian Gulf & Oman Sea and Indian Ocean. In this study, CMSY method was used to determine the biological reference points (BRPs) of Indo-Pacific king mackerel in the two mentioned study area. Catch data was collected from 1997-2022 and 1950 -2022 in the Persian Gulf & Oman Sea and Indian Ocean, respectively. The average catch of the Persian Gulf & Oman Sea was 5750 tons in the studied period. The average (minimum -maximum) of carrying capacity (K), maximum sustainable yield (MSY), the biomass of maximum sustainable yield (B_{msy}), current biomass (B) and Fishing mortality of maximum sustainable yield (F_{msy}) were obtained by the Catch- maximum sustainable yield (CMSY) method. F/F_{MSY} was estimated 1.11 and 0.69 in the Indian Ocean and Persian Gulf & Oman Sea, respectively. B/B_{MSY} was identified less than 1 in the Indian Ocean. The KOBE plot indicates that based on the CMSY model results, Indo-Pacific king mackerel is currently overfished (B_{2022}/B_{MSY}=0.97) and is subject to overfishing (F_{2022}/F_{MSY} = 1.11) in the Indian Ocean, but the current stock situation is not overfished (B_{2022}/B_{MSY}=1.35) and not subject to overfishing (F_{2022}/F_{MSY} = 0.69) in the Iranian southern waters.

Keywords: Indo-Pacific king mackerel, CMSY, BRPs, Indian Ocean, Persian Gulf, Oman Sea

Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is challenging due to the paucity of data. There is lack of reliable information on stock structure, abundance and biological parameters. Stock assessments have been conducted for Indo pacific king mackerel (*Scomberomorus guttatus*) in 2015 ,2016 and 2021 using data-limited methods (Martin & Sharma,2015; Martin & Robinson ,2016; Fu, 2021). This paper provides an update to the CMSY assessment based on the most recent catch information.

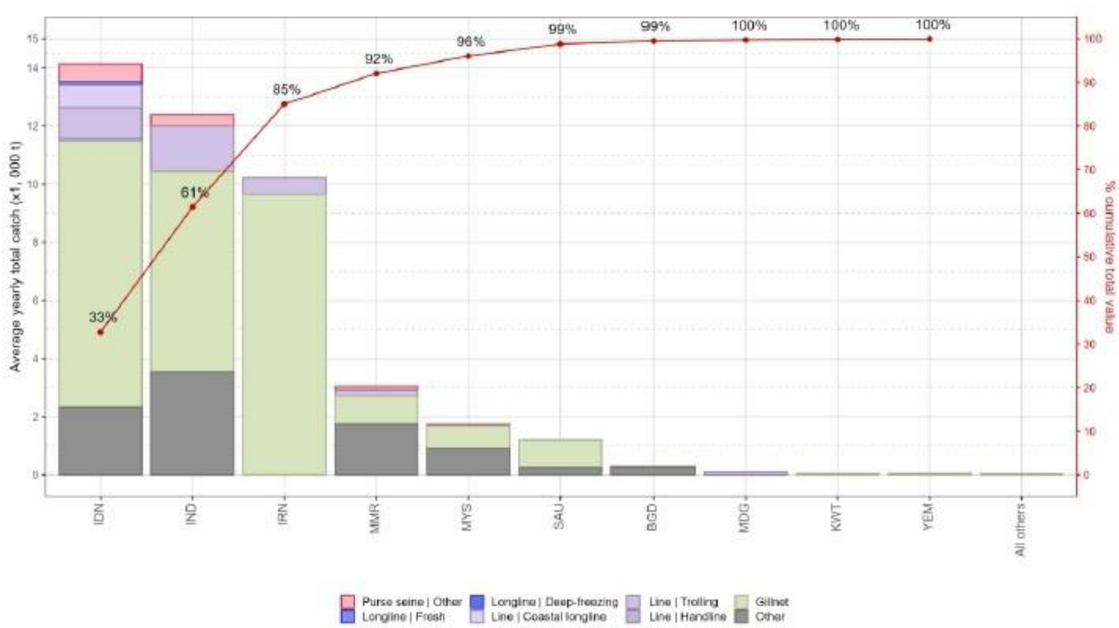

Fig 1. Mean annual catches (t) of Indo-pacific king mackerel by fleet and fishery between 2018 and 2022, with indication of cumulative catches by fleet (IOTC–2023–SC26)

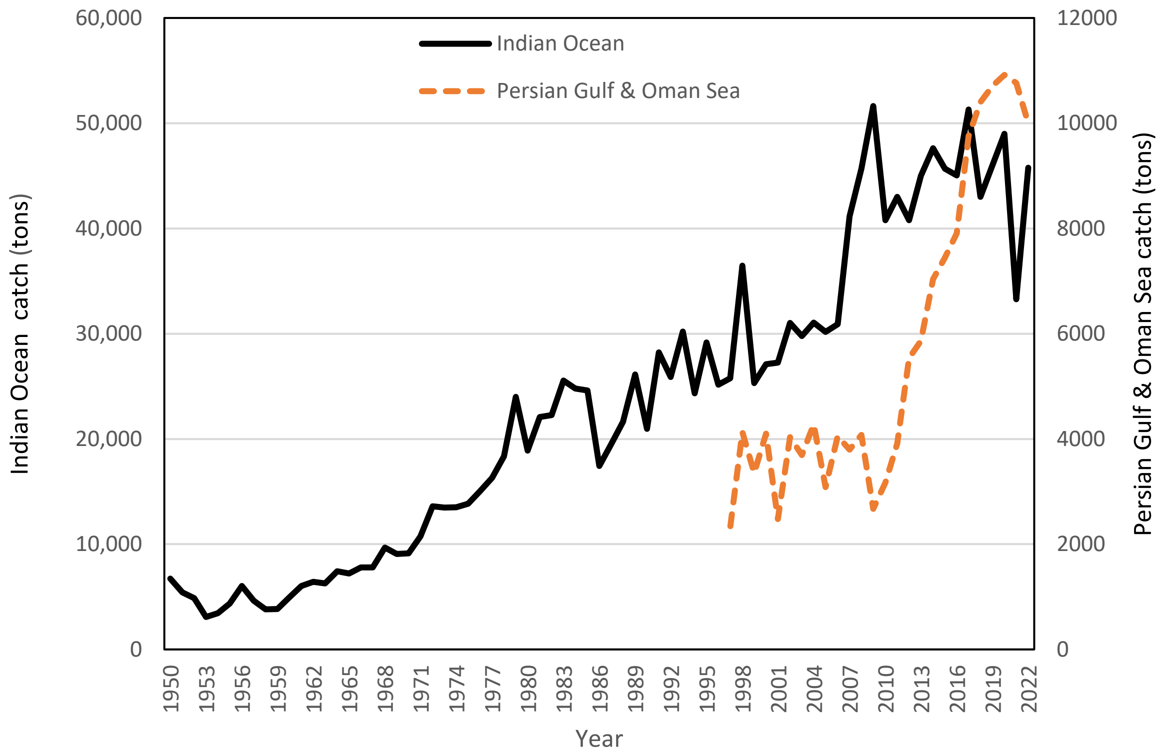

Fig 2. IOTC nominal catch data for *S. guttatus* from 1997 -2022 for the Persian Gulf & Oman Sea and 1950 -2022 for Indian Ocean

Table 1. Catch data for *S. guttatus* in the Persian Gulf & Oman Sea, 1997-2022 (Source: IOTC Database) (IFO,2023)

YEAR	CATCH(T)	YEAR	CATCH(T)
1997	2342	**2010**	3170
1998	4129	**2011**	3913
1999	3350	**2012**	5537
2000	4100	**2013**	5863
2001	2474	**2014**	7037
2002	4031	**2015**	7447
2003	3695	**2016**	7908
2004	4279	**2017**	9754
2005	3088	**2018**	10399
2006	4050	**2019**	10710
2007	3797	**2020**	10918
2008	4078	**2021**	10763
2009	2669	**2022**	10002

Table2. Catch data for *S. guttatus* in the Indian Ocean, 1950-2022 (Source: IOTC Database)

YEAR	CATCH(T)	YEAR	CATCH(T)
1950	6,744	1987	19,503
1951	5,431	1988	21,637
1952	4,871	1989	26,135
1953	3,083	1990	20,951
1954	3,461	1991	28,237
1955	4,368	1992	25,881
1956	6,035	1993	30,210
1957	4,636	1994	24,338
1958	3,824	1995	29,162
1959	3,844	1996	25,154
1960	4,971	1997	25,763
1961	6,026	1998	36,471
1962	6,420	1999	25,316
1963	6,282	2000	27,101
1964	7,415	2001	27,263
1965	7,230	2002	31,012
1966	7,780	2003	29,768
1967	7,803	2004	31,061
1968	9,678	2005	30,159
1969	9,081	2006	30,915
1970	9,132	2007	41,148
1971	10,740	2008	45,684
1972	13,587	2009	51,631
1973	13,484	2010	40,787
1974	13,497	2011	42,997
1975	13,847	2012	40,779
1976	15,040	2013	45,021
1977	16,307	2014	47,617
1978	18,331	2015	45,682
1979	24,015	2016	45,043
1980	18,878	2017	51,313
1981	22,074	2018	43,007
1982	22,265	2019	46,053
1983	25,553	2020	48,986
1984	24,798	2021	33,266
1985	24,603	2022	45,769
1986	17,420		

The quantity and quality of data from many fisheries in the world are insufficient to allow for the application of conventional assessment methods. Management of "data-rich" stocks approaches are often based on complex stock assessment models and it needs a variety of data sources. Right now, stock management is faced with different fish stocks that have little data that don't support these with data-rich approaches (Dick & MacCall, 2011).Today, Length-based models, such as Length Based Spawning Potential Ratio (LBSPR), Length-Based Integrated Mixed Effects (LIME), Length-Based Bayesian (LBB), and as well as catch-based methods, such as Catch-Maximum Sustainable Yield (Catch-MSY), Depletion Based Stock Reduction Analysis (DBSRA), Simple Stock Synthesis (SSS), Catch-MSY (CMSY), in many fishery scenarios and in different countries have been developed (known as "data-poor" or "data-limited" fisheries) (Wetzel & Punt, 2015).

The tuna & tuna like fisheries have a major role in Iranian subsistence fisheries in comparison with other activities in the southern coastal provinces. Gillnet, longline and purse seine are the main fishing methods used by Iranian vessels to target large pelagics (especially tuna and tuna like species) in the IOTC area competence. Total catch of the Persian Gulf & Oman Sea was estimated around 718,000 tons in 2022, which the contribution of the large pelagic species was 344677 tons (around 288735 tons belongs to tuna and tuna-like species. This amount of the catch mainly comprised of tropical tuna with 42.8 % (123343 tons), neritic tuna 45.2 % (130576 tons) and billfish species with 12% (34,816 tons) (IFO,2023).

The *S. guttatus* is inhabiting coastal waters up to 200 meters (usually up to 90 meters) and sometimes entering turbid estuarine waters; usually found in small schools. This species has a maximum length of 76 cm (usually about 40 cm) and a maximum weight near 5 kg (Collette & Nauen, 1983). The *S. guttatus* is one of the tuna- like species which is caught by the gillnet fishery in the Southern Iranian Waters. Almost 85% of mean annual catches of Indo-Pacific King Mackerel are accounted for fisheries by Indonesia, India and Iran between 2018 and 2022 in the Indian Ocean (Fig 1) (IOTC–2023–SC26).

Material & Methods

The CMSY method of Froese et al. (2017) was applied to estimate reference points from catch, resilience, and qualitative stock status information for the Indo-Pacific king mackerel in the two studied areas, (i) Persian Gulf and Oman Sea, (ii) Indian Ocean. The CMSY method represents a further development of the Catch-MSY method of Martell & Froese (2013), with a number of

improvements to reduce potential bias. Like the Catch-MSY method, The CMSY relies on only a catch time series dataset, which was available from 1950 – 2022 in the Indian Ocean and from 1997 - 2022 in the Persian Gulf & Oman Sea, prior ranges of r and K, and possible ranges of stock sizes in the first and final years of the time series (Table 1,2)(Fig 2) (www.iotc.org ; IFO,2023).

Determining the boundaries of the r-k space

To determine prior r-ranges for the species under assessment, the proxies for resilience of the species as provided in Fish Base (Froese et al., 2000) were translated into the r-ranges shown in Table 3. The proxy for the resilience of *S. guttatus* in the Fish Base is" medium" and translated into prior r-ranges 0.2 to 0.8.

Table 3. Prior ranges for parameter r, based on classification of resilience in Fish Base (Froese & Pauly, 2015).

Resilience	Prior *r*-range
High	0.6–1.5
Medium	0.2–0.8
Low	0.05–0.5
Very low	0.015–0.1

The prior range of relative biomass at the beginning and end of the time series along with an intermediate year estimated automatically by the default rules of this method from the three biomass ranges; low (0.01–0.4), medium (0.2–0.6), and high (0.5–0.9) (Froese et al., 2017).

The Graham-Shaefer surplus production model (Shaefer ,1954) is used (equation,(1, where B_{t+1} is the exploited biomass in the subsequent year t+1, B_t is the current biomass, and C_t is the catch in year t.

$$B_{t+1} = B_t + r\left(1 - \frac{B_t}{k}\right)B_t - C_t \qquad (1)$$

The r-k and predicted biomass trajectory is considered viable if the predicted biomass is not smaller than 0.01 k and falls within the range of prior biomass of the intermediate and final year. From the ranges of" viable" r-k pair, CMSY estimated the most probable values of r and k by the method's default rules. Then the MSY and related fisheries reference points are calculated as MSY = r k/4, fishing mortality corresponding to MSY (F_{MSY}) = 0.5 r, and the biomass below which recruitment may be compromised is half of B_{MSY} (B_{MSY}) = 0.5k .(Haddon et al., 2012; Carruthers et al., 2014; Froese et al., 2015) (Zhou et al., 2017).

In this method, the values of population intrinsic growth rate and carrying capacity are calculated with depletion formula (d) and storage saturation (S) according to following (equation,2,3):

$$d = 1 - s \qquad (2)$$

$$S = 1 - \frac{Bt}{k_t} \qquad (3)$$

C-MSY estimates biomass, exploitation rate, MSY and related fisheries reference points from catch data and resilience of the species. Probable ranges for r and k are filtered with a Monte Carlo approach to detect 'viable' r-k pairs. The model worked sequentially through the range of initial biomass depletion level and random pairs of r and K were drawn based on the uniform distribution for the specified ranges. Equation 1 is used to calculate the predicted biomass in subsequent years, each r-k pair at each given starting biomass level is considered variable if the stock has never collapsed or exceeded carrying capacity and that the final biomass estimate which falls within the assumed depletion range. All r-k combinations for each starting biomass which were considered feasible were retained for further analysis. The search for viable r-k pairs is terminated once more than 1000 pairs are found.

The most probable r-k pair were determined using the method described by Froese et al. (2016). All viable r-values are assigned by the method's default rules. The 75th percentile of the mid-values of occupied bins is taken as the most probable estimate of r. Approximate 95% confidence limits of the most probable r are obtained as 51.25th and 98.75th percentiles of the mid-values of occupied bins, respectively. The most probable value of k is determined from a linear regression fitted to log(k) as a function of log(r), for r-k pairs where r is larger than median of mid-values of occupied bins. MSY are obtained as geometric mean of the MSY values calculated for each of the r-k pairs where r is larger than the median. Viable biomass trajectories were restricted to those associated with an r-k pair that fell within the confidence limits of the CMSY estimates of r and k (Table 4). The maximum

steady-state mortality rate with the aid of formula FMSY = r /2 and the maximum sustainable yield is calculated from MSY = r k / 4 and B_{MSY} = K / 2 (Zhou et al., 2017).

Table 4. Relative biomass, ranges for r, k as priors in CMSY of *S. guttatus* in the Persian Gulf & Oman Sea and Indian Ocean

Input Parameters (Ranges of the values)	**Prior Initial Relative Biomass**	**Prior Intermediate Relative Biomass**	**Prior Final Relative Biomass**	**Prior Range for r**	**Prior Range for k tons**
Persian Gulf & Oman Sea	0.2 - 0.6	0.5 - 0.9 **In Year 2018**	0.4 - 0.8	0.2 - 0.8	27000-648000
Indian Ocean	0.5 - 0.9	0.2 - 0.6 **In Year 2016**	0.4 - 0.8	0.2 - 0.8	118000 -2841000

Results

Persian Gulf & Oman Sea

The amount of catch was 7908 tons in 2016 which increased to10002 tons in 2022, The mean catch (Ct) for the studied period (1997-2022) was 5750 tons (95% confidence interval 5514-5985 tons)

The initial intrinsic growth rate (r) and initial relative biomass(B) were 0.2- 0.8 and 0.2-0.6, respectively. The output values of the model after Monte Carlo simulations were obtained (Fig 3 and Table 5). The mortality fishing (F) to mortality fishing of the maximum sustainable yield (F_{msy}) ratio (F / F_{msy}), intrinsic growth rate (r) and present fishing mortality(F) in the

CMSY model were 0.93(0.79-1.53), 0.56 (0.4 – 0.78) and 0.26 (0.22- 0.42) (in 2022 year), respectively.

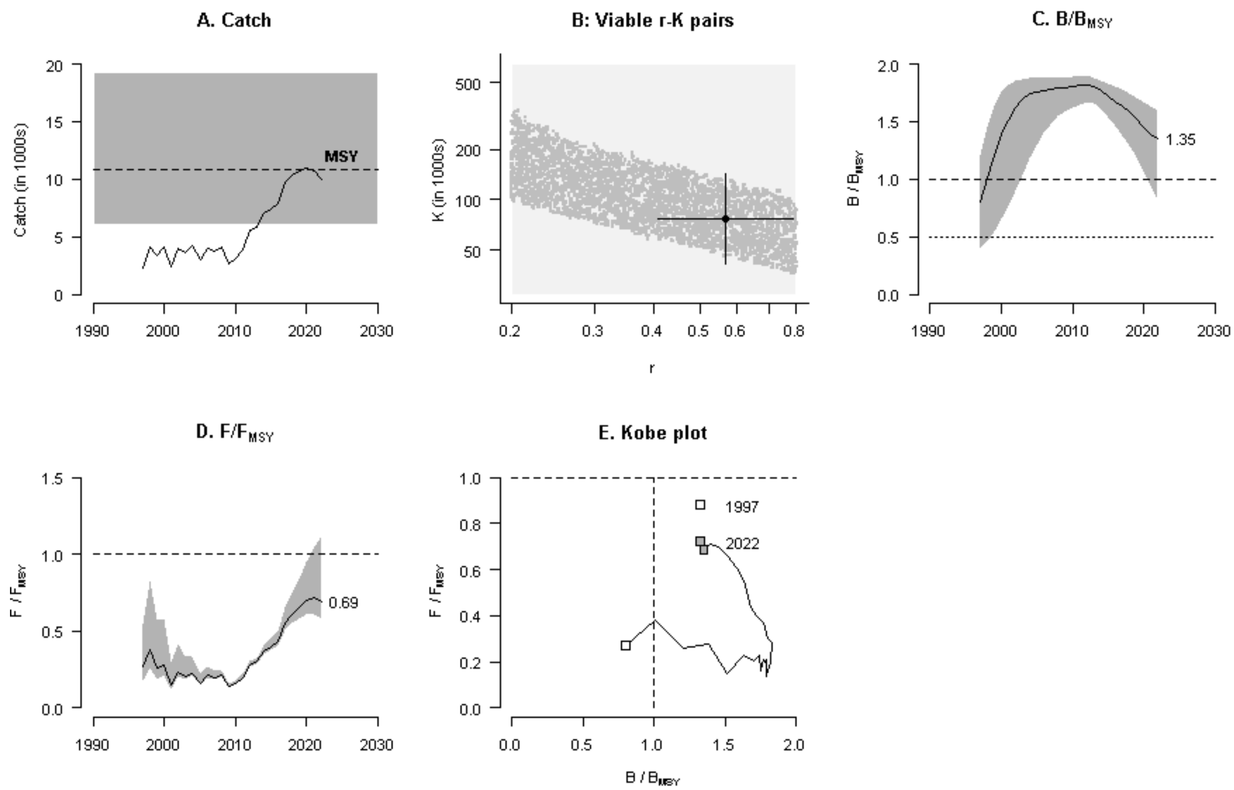

Fig 3. Results of CMSY reference model for Indo-Pacific King Mackerel in the Persian Gulf & Oman Sea

Indian Ocean

The amount of catch was 10740 tons in 1971 which increased smoothly year by year and became 45769 tons in 2022, The mean catch (Ct) for the studied period (1950-2022) was 23059 tons (95% confidence interval 19662 -26457 tons).

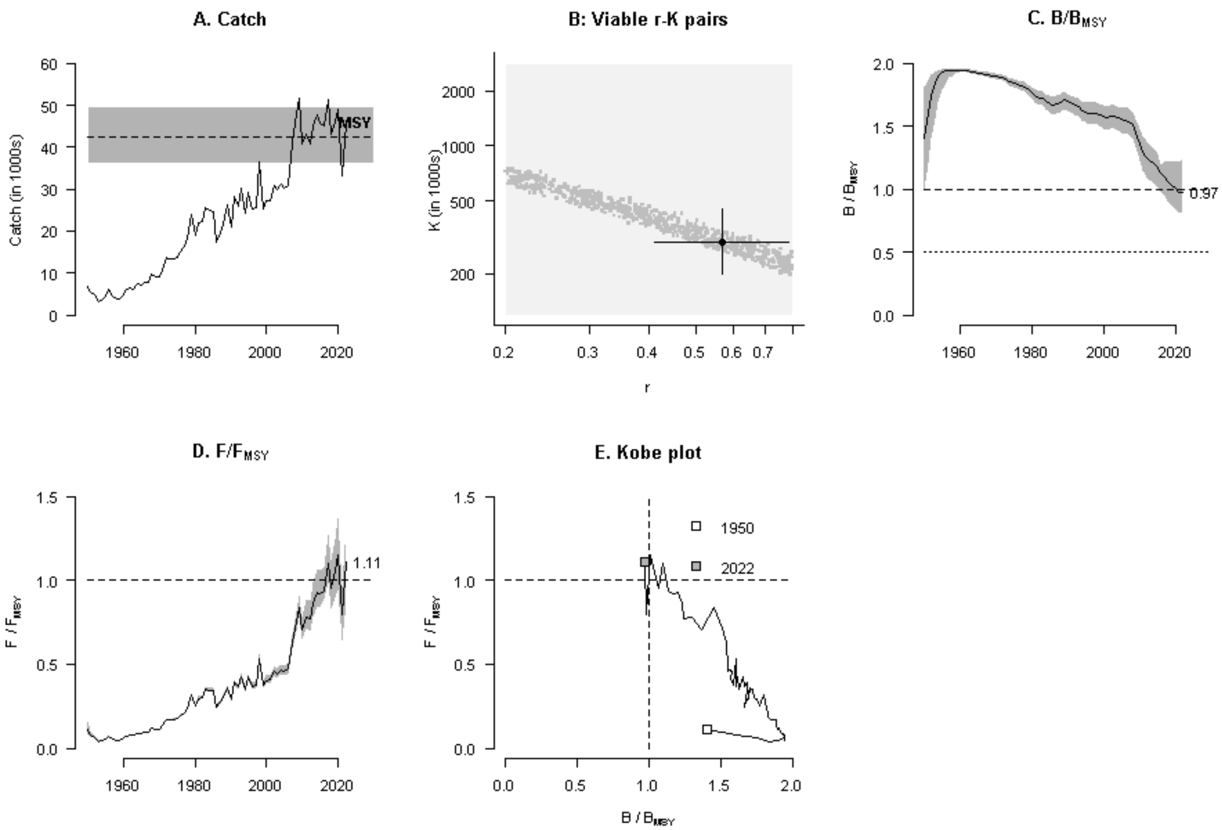

Fig 4. Results of CMSY reference model for Indo-Pacific King Mackerel in the Indian Ocean

The initial intrinsic growth rate (r) and initial relative biomass(B) were 0.2- 0.8 and 0.5-0.9, respectively. The output values of the model after Monte Carlo simulations were obtained (Fig 4 and Table 5). The mortality fishing (F) to mortality fishing of the maximum sustainable yield (F_{msy}) ratio (F / Fmsy), intrinsic growth rate (r) and present fishing mortality(F) in the CMSY model were 0.93(0.79-1.53), 0.566 (0.407 – 0.78) and 0.686 per year (in 2022 year), respectively.

Estimates from the C-MSY model suggested that currently the stock of Indo-Pacific king mackerel in the Persian Gulf & Oman Sea is not overfished ($B_{2022} > B_{MSY}$) and is not subject to overfishing ($F_{2022} < F_{MSY}$). The CMSY estimated a mean MSY of approx. 10 800 t. Reported catches of Indo-Pacific king mackerel in the Iranian Waters have been considerably stable for five years ago. The catch in 2022 was lower than the estimated MSY. Despite the substantial uncertainties described

throughout this paper, this suggests that the stock is being fished lower than MSY levels and that higher catches may not be sustained. A precautionary approach to management is recommended.

Table 5. Key prediction of fisheries reference point indicators for Indo pacific king mackerel in the Persian Gulf & Oman Sea and Indian Ocean

(values in parenthesis represent 2.5th and 97.5th percentiles)

Parameter	Persian Gulf & Oman Sea	Indian Ocean
r	**0.566 (0.407-0.785)**	**0.568 (0.411-0.758)**
K (thousands tons)	**76.5 (41.1-142)**	**299 (200-448)**
Biomass *(thousands tons)*	**51.6 (31.7-60.9)**	**145 (121-185)**
MSY *(thousands tons)*	**10.8 (6.09-19.2)**	**42.5 (36.3- 49.8)**
F_{MSY}	**0.283 (0.204-0.392)**	**0.284 (0.206-0.393)**
B_{MSY}	**38.3 (20.6-71.2)**	**149 (99.8-224)**
B/B_{MSY} (last year)	**1.35 (0.828-1.59)**	**0.97 (0.808 -1.24)**
Fishing mortality(per year)	**0.194 (0.164-0.316)**	**0.316 (0.247-0.379)**
B_{MSY}/K	**0.500 (0.501-0.501)**	**0.498 (0.499-0.5)**
F/F_{MSY}	**0.686 (0.581-1.12)**	**1.11 (0.87-1.33)**
Relative biomass (last year)	**0.674 *k* (0.414-0.796)**	**0.485 *k* (0.404 -0.619)**
Exploitation F/(r/2) (last year)	**0.686**	**1.11**

Estimates from the CMSY model suggested that the stock of Indo-Pacific king mackerel is currently overfished ($B_{2022} < B_{MSY}$) and is subject to overfishing ($F_{2022} > F_{MSY}$) in the Indian Ocean, although the estimates would be more pessimistic if the stock productivity is assumed to be less resilient. The CMSY estimated a mean MSY of approx. 42 500 t. Reported catches of Indo-Pacific

king mackerel in the Indian Ocean has increased considerably since the late 2000s, with recent catches ranging between 40600 and 51600. The catch in 2022 was more than the estimated MSY. Despite the substantial uncertainties described throughout this paper, this suggests that the stock is being fished higher than MSY levels and that higher catches may not be sustained. A precautionary approach to management is recommended.

Discussion

Persian Gulf & Oman Sea

The population instantaneous growth rate (r) is one of the important inputs in the modeling and fisheries management for determining the population growth, the ability to withstand the catch pressure, and the recovery and renewal of the population (Zhou et al., 2016). it is necessary to find the limits of this parameter (Froese & Pauly, 2015). The different species divided with the population instantaneous growth rate (r) values of 0.6-1.5 (high flexibility), 0.2-0.8 (moderate flexibility), 0.05-0.5 (low flexibility) and 0.015 - 0.1 (very low flexibility) (Froese et al., 2016; Martell & Froese., 2013). Between this parameter (r) and other life history parameters is a significant relationship. Then the MSY and related fisheries reference points are calculated as MSY = r k/4, fishing mortality corresponding to MSY (F_{MSY}) = 0.5r, biomass corresponding to MSY (B_{MSY}) = 0.5k (Schaefer,1954; Ricker ,1975).

One of the important indicators of Biological Reference Points (BRP) is the biomass of the maximum sustainable yield to carry capacity or stock status (B_{msy} / K), and this indicator of this species is shown near 0.5 (CMSY method) and 0.39 (DBSRA method), that represents the Medium (0.2-0.6) depletion rate (Palomares & Froese, 2017). Generally, the optimal proportion of this ratio varies from species to species, and is usually between 30% and 60%. Fish species with higher population intrinsic growth rates has less rates of B_{msy} / K (also vice versa). Ultimately this index is considered to be between 30% and 20%, and less than this value shows a sharp decrease in fish stock (Gabriel & Mace, 1999). Undoubtedly, the exploitation rate and population biomass change with population intrinsic growth rates (r) and B_{msy} / K ratio (Zhou et al., 2016). This study shows that the annual catch (about 10 thousand tons in 2019) exceeds the maximum sustainable yield (MSY) of this species in the Iranian Waters (Hashemi & Doustdar, 2022), meanwhile the catch in 2022 was lower than the estimated MSY in our study.

The catch-maximum sustainable yield (CMSY) and the Bayesian surplus production (BSM) models from catch data (1997-2019) were also used to determine the sustainable exploitation and fisheries reference points of *S. guttatus* caught in the southern waters of Iran. In this study, by applying the forecasting model, the increasing trend of fishing was predicted in 2033. If this trend continues, the value of B/B_{MSY} will fall below 1.0 and the value of F/F_{MSY} will increase to about 1.99. If the catch is not reduced from 2028, the stock will start to be decreased in the years after 2030 and the stock will be overfished. Based on the obtained fisheries reference points, the maximum sustainable yield (MSY) was estimated as 9,000 tons, and this amount was predicted to be 15,000 tons in 2033. In general, the estimated fisheries reference points in this study can be an effective aid in understanding the status of *S. guttatus* stock in the southern waters of Iran and reveal the effects of the application of management policies on its stocks, which can ultimately develop compatible management plans for proper exploitation of its stocks in the region (Haghi Vayghan & Ghanbarzadeh, 2022).

Indian Ocean

Results between the catch-MSY and OCOM method were very similar with MSY estimated at 44 000 t based on the Catch-MSY model and 43 000 t based on the OCOM model. Both models indicated that *S. guttatus* is 'not overfished' (B_{2013}/B_{msy} = 1.04; 1.01), and as $F2_{013}/F_{msy}$ = 1.00 and 1.05 for the two model approaches used, the stock is considered to be 'subject to overfishing'. The catch in 2013 was reported to be 46 354 t which, while lower than the average of the previous 5 years (49 870 t), is still higher than both estimates of MSY (Martin& Sharma,2015).

Both catch-MSY & OCOM models indicated that *S. guttatus* is not currently overfished with B_{2014}/B_{MSY} estimated at 1.06 and 1.10 for the Catch-MSY and OCOM models, respectively. Results of the alternative OCOM run also indicate that the stock is not overfished (B_{2014}/B_{MSY} = 1.05). However, there is discrepancy between the models in terms of the mortality-based indicator. As was the case in 2015, the Catch-MSY model indicated the Indo-Pacific king mackerel is subject to overfishing with an $F_{2014}/\ F_{MSY}$ ratio of 1.02. Though run 1 of the OCOM model suggested that overfishing is not occurring (F_{2014}/F_{MSY} = 0.98), results from the alternative run corresponded to those of Catch-MSY (F_{2014}/F_{MSY} = 1.03). Therefore, based on the weight-of-evidence currently available, it is likely that the stock is not currently '*overfished*' but is '*subject to overfishing'*.

There are substantial uncertainties that are described throughout this paper and these ratios are borderline, being very close to 1. This suggests that the stock is very close to being fished at MSY levels and that higher catches could not be sustained. A precautionary approach to management is recommended.

Given that the assessments conducted are data-poor methods with considerable uncertainty and that both are based primarily on the catch data and an underlying Schaefer model, alternative assessment methods using different data and alternative assumptions should be used to explore the status of the Stock further (Martin & Robinson).

Estimates from the CMSY model suggested that currently the stock of Indo-Pacific king mackerel in the Indian Ocean is not overfished ($B_{2019} > B_{MSY}$) and is not subject to overfishing ($F_{2019} < F_{MSY}$), although the estimates would be more pessimistic if the stock productivity is assumed to be less resilient. The CMSY estimated a mean MSY of approx. 46 900 t with a relatively wider range. Reported catches of Indo-Pacific king mackerel in the Indian Ocean has increased considerably since the late 2000s, with recent catches ranging between 40600 and 51600. The catch in 2019 was below the estimated MSY. Despite the substantial uncertainties described throughout this paper, this suggests that the stock is very close to being fished at MSY levels and that higher catches may not be sustained. A precautionary approach to management is recommended (Fu, 2021).

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