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Original Article

Stock Assessment of Indo-Pacific King Mackerel, *Scomberomorus guttatus* (Bloch & Schneider, 1801) in the Persian Gulf and Oman Sea, southern Iranian waters, using CMSY and DBSRA

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Abstract: The purpose of this study was to investigate the catch trend and estimation of the optimized catch limit of the *Scomberomorus guttatus* (GUT) stock by collecting catch data in southern Iranian waters. In this study, two methods were used to determine the biological reference points (BRPs) of Indo-Pacific king mackerel in southern Iranian waters i.e. the Persian Gulf and Oman Sea. Catch data was collected for 23 years (1997-2019), and the optimized catch limit was estimated using a limited data approach and R Software. The average catch (Ct) for this period was 5123 tonnes (95% confidence interval 4026 -6218 tonnes), and it had significantly increased over the past two decades. The average (maximum-minimum) of carrying capacity (K), maximum sustainable yield (MSY), the biomass of maximum sustainable yield (Bmsy), current biomass (B) and fishing mortality of maximum sustainable yield (Fmsy) were obtained by the Depletion-Based Stock Reduction Analysis (DBSRA) and Catch- maximum sustainable yield (Cmsy) models. The Bmsy and K in two models showed no significant difference from the one-sample t-test at $P>0.05$. The results revealed that the exploitation ratio in the Indo-Pacific king mackerel stock is full fishing (full exploitation), and do not suggest an increase in exploitation ratio and fishing effort are proposed.

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Introduction

The quantity and quality of data from many fisheries globally are not enough for using traditional assessment procedures. Management of “data-rich” stocks approaches is often based on complex stock assessment models that need a variety of data sources. Some fishes have little data that do not support these data-rich approaches (Dick and MacCall, 2011). Today, length-based models, such as Length-Based Bayesian (LBB), Length-Based Integrated Mixed Effects (LIME), Length Based Spawning Potential Ratio (LBSPR), and catch-based methods, such as Depletion Based Stock Reduction Analysis (DBSRA), Catch-Maximum Sustainable Yield (Catch-MSY), Catch-MSY (CMSY), as well as Simple Stock Synthesis (SSS) have been developed (a “data-poor” or “data-limited” fisheries) in many fishery scenarios and different countries (Wetzel and Punt, 2015).

The fishery for tuna and tuna-like species is a main section in the pelagic fisheries in Iran and a key activity in the Oman Sea and the Persian Gulf. Therefore, its fishery management requires a lot of data, and for this purpose, Iran Fishery Data Collection System (IFDCS) has been established and developed since 1994 (IFSY, 2020). Purse seine and gillnet have been proposed as the two key fishing techniques for the Iranian vessels for targeting large pelagic species, in particular, tuna and tuna-like fishes in the IOTC area, and also, several little boats are used for trolling in the coastal fisheries. In 2019, total fisheries catch production in Iran was about 800,000 t that the tuna and tuna-like species were near 300,000t of this yearly catch i.e. nearly its 20% was yellowtail tuna (IFSY, 2020).

Tuna fishes are members of the family Scombridae with 52 species (Collette and Nauen, 1983; Froese and Pauly, 2018). The genus *Scomberomorus* has 18 species that two of which

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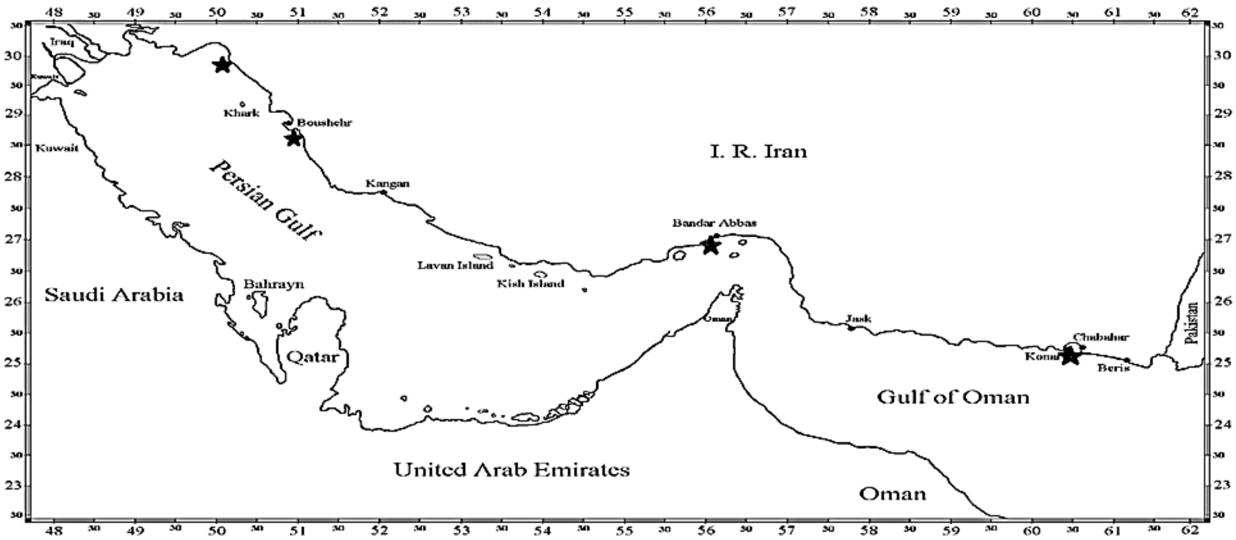

Figure 1. Map of study area and main Iranian fishing ports (Stars denoted the fishing ports).

are found in the Persian Gulf and the Oman Sea (Kaymaram et al., 2009). Indo-Pacific king mackerel is an epipelagic migratory species in tropical and subtropical regions across the western Pacific and Indian oceans. This species inhabits coastal waters up to 200 m (usually up to 90 m) and sometimes enters turbid estuarine waters, usually in small schools. This species has a maximum length of 76 cm (usually about 40 cm) and a maximum weight of nearly 5 kg (Collette and Nauen, 1983; Froese and Pauly, 2018). The *S. guttatus* is one of the important economic tuna fishes throughout tropical and subtropical seas. It catches near 50 thousand tons in the world (FAO, 2018) and nearly 45 thousand tons in the Indian Ocean (IOTC, 2020). Indo-Pacific King mackerel are mainly caught by gillnets (≈66%) in the Indian Ocean. Almost two-thirds of catches are accounted for by fisheries in India and Indonesia, with important catches reported by Iran (IOTC, 2020).

The Oman Sea and the Persian Gulf, which have their unique ecological conditions, host various aquatic species that provide livelihood, employment, and different economic activities for the settlers (Taghavimotlagh and Shojaei, 2017). Iran has more than 120,000 fishermen, whose main job is fishing, and fishing has played a major role in their employment in coastal areas and in economic activities for post-harvest operations (Taghavimotlagh, 2010).

Various studies are performed on different tuna species within the world (John and Reddy, 1989; Chantawong, 1998; Kaymaram et al., 2000; Tantivala, 2000; Somvanshi et al., 2003; Prathibha et al., 2012; Ramalingam et al., 2012; Kaymaram et al., 2014; Nurdin et al., 2016; Haruna et al., 2018). Despite the economic importance of the Indo-Pacific King mackerel, its assessment is not very well-understood. Different aspects of the biological work of tuna fish have been done in Iran by (Kaymaram et al., 2000; Kaymaram et al., 2014; Darvishi et al., 2017; Yasami et al., 2018; Vayghan et al., 2020; Hashemi et al., 2020), but no work has been done on stock assessment of this fish species in the southern Iranian waters, i.e. Oman Sea and the Persian Gulf. However, Fisheries Reference Points (FRP) are a significant issue affecting the management of fisheries. Their exploitation and stock status are unknown in several of the world's fisheries stocks (Froese et al., 2012) and Iranian ones. Hence, the present study is the first step to investigate fishing trends for this species in Southern Iranian waters to identify fisheries reference points and the optimal fishing range of *S. guttatus* stock.

Materials and Methods

Study area and Fishery data: The study area covers four main Iranian fishing ports (Khuzestan, Bushehr, Bandar Abbas, and Chabahar) in the water of the

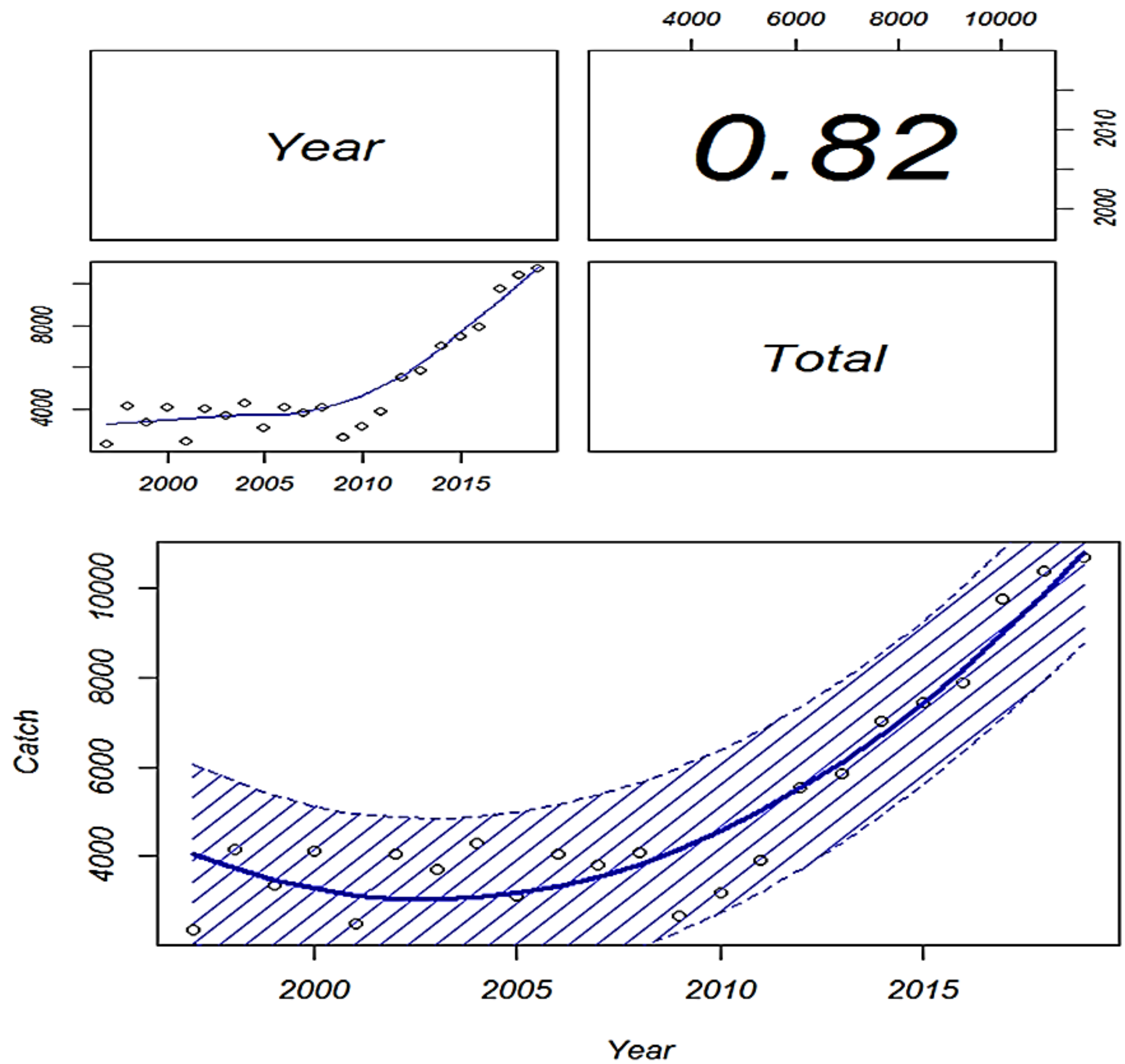

Figure 2. Changes of annual (year) catch (Catch or Total) trend for Indo-Pacific king mackerel in the Oman Sea and Persian Gulf.

Oman Sea and northern Persian Gulf (Fig. 1). Moreover, we collected data on *S. guttatus* fishery from the logbooks of Iranian drift gillnets fishing fleets in the southern Iranian waters that have been provided by the Iranian Fisheries Organization (IFO). Data from 1997 to 2019 were gathered for calculation and inputted into the model (Fig. 2).

Model development and data analysis: The data-poor methods have been widely used in fish stock assessment, where time series of catch records are available (Froese et al., 2017; Zhou et al., 2019). There are two interesting methods —CMSY (Martell and Froese, 2013; Froese et al., 2017).

Catch-MSY (CMSY): The Catch-MSY model has the same characteristics as the Graham-Shaefer surplus production model. These models rely on only a catch time-series dataset and earlier ranges of k and r, and the probable range of the size of the stock at the beginning and last years of the time series. According to the studies in the field, CMSY has been proposed as one of the methods for estimation of the MSY and respective FRP (Bmsy, Fmsy) from information on resilience and catch data (Froese et al., 2017). This model needs a prior distribution on K and r and the priors on the relative proportion of bio-mass at the initial phase (Martell and Froese, 2013). Biomass in subsequent years was then generated from a Schaefer model according to the Equation of $B_{y+1} = B_y + rB_y (1- B_y / k) es^1 - Ct\, es^2$, where By = Biomass in the year y+1, r = population instantaneous growth rate, K = carrying capacity, and Cy = catch in the time series In this method, the values of population instantaneous

Table 1. Comparison of different indices of CMSY models for Indo-Pacific king mackerel in the Oman Sea and Persian Gulf.

Indices / models	CMSY Average (Maximum-minimum)	DBSRA Average (Maximum-minimum)
Biomass (1000 tonnes)	40.5 (24.8-47.5)	20 (14.11-60)
MSY (1000 tonnes)	8.44 (4.65-15.30)	6.46 (4.62-12.40)
Bmsy (1000 tonnes)	29.8 (15.9-56.2)	24.7 (16.8-43.30)
Fmsy	0.28 (0.20-0.39)	0.45 (0.22-0.99)
B/Bmsy	1.36 (0.83-1.59)	0.8 (0.25-1.38)
K (1000 tonnes)	59 (31-112)	63.60 (38.70-104)
Bt/K	0.68 (0.4-0.78)	0.31 (0.1-0.5)
Bmsy/K	0.50	0.39

growth rate and carrying capacity are calculated with depletion formula (d) and storage saturation (S) as d = 1- S = 1- By / Ky.

The maximum steady-state mortality rate was calculated using Fmsy = r / 2 and the maximum sustainable yield from MSY = rk / 4 and Bmsy = K / 2 (Zhou et al., 2017). es^1 and es^2 are related to processing error and observation error, respectively. The rule of thumb of r = 2FMSY = 2M is a prevailing assumption when population dynamics are evaluated by the Schaefer surplus production model (Quinn and Deriso 1990). A Prior range for the parameter r with the resilience categorization in FishBase (Froese and Pauly, 2019), also proposed by Martell and Froese (2013), was set as 0.2-0.8 as *S. guttatus* (GUT*)* placed in medium resilience.

DBSRA methods: The Depletion-Based Stock Reduction Analysis (DBSRA) (Dick and MacCall, 2011) merges stochastic Stock-Reduction Analysis (SRA) (Kimura et al., 1984) with Depletion-Corrected Average Catch (DCAC) (MacCall, 2009). This method with Monte Carlo simulations generates the distribution of the approximated bio-mass as well as other reference points like MSY, spawning bio-mass that creates MSY (Bmsy), and fishing mortality at MSY (Fmsy) (NMFS, 2009). This employs a delay-difference production approach with a time lag for mortality and recruitment as: $B_{t+1} = B_t + P(B_{t-Amat}) - C_{t-1}$, where C represents the catch, Bt refers to bio-mass at time t, P stands for the latent annual production according to the parental bio-mass in year t-Amat, and Amat is the age at the entry to the reproductive biomass. Furthermore, bio-mass in the first year (B0) has been considered to be equal to K. DB-SRA distributions have been regarded with this assumption: recent stock bio-mass equaled 40% of the unfished biomass (B/K = 0.4), and estimate of MSY, Bmsy, and K with lower values of B/K usually lessen the absolute relative error. For DBSRA, we used the approximate age at maturity (Amat = 2), and natural mortality (M = 0.6) *(*Froese and Pauly, 2019). All have been allocated to distribution so that it is possible to draw the Monte Carlo from it*.*

Statistical analysis: The statistical analysis was performed using R (R Core Team, 2018) package "Catch-MSY"and"fishmethods*"* (Nelson, 2017)*,* R studio (1.1.446) software, and SPSS (26), and the significance level and confidence interval were 0.05 and 95%, respectively.

Results

The average catch (Ct) for the study period was 5123 tonnes (95% confidence interval 4026-6218 tonnes), and it (r = 0.82, *P*<0.05) had significantly increased over the past two decades.

CMSY and DBSRA methods: The average (95% confidence interval) of carrying capacity (K), MSY, the Bmsy, current biomass (B), as well as Fmsy were obtained by the *DBSRA* and Cmsy models (Figs. 3, 4; Table 1). In CMSY *method*, the initial intrinsic growth rate (r) and initial relative biomass (B) were 0.6-1.2 and 0.5-0.9, respectively. The output values of the model after 30000 Monte Carlo simulations were obtained (Fig. 3; Table 1). The mortality fishing (F) to mortality fishing of the maximum sustainable yield (Fmsy) ratio (F / Fmsy), intrinsic growth rate (r), and

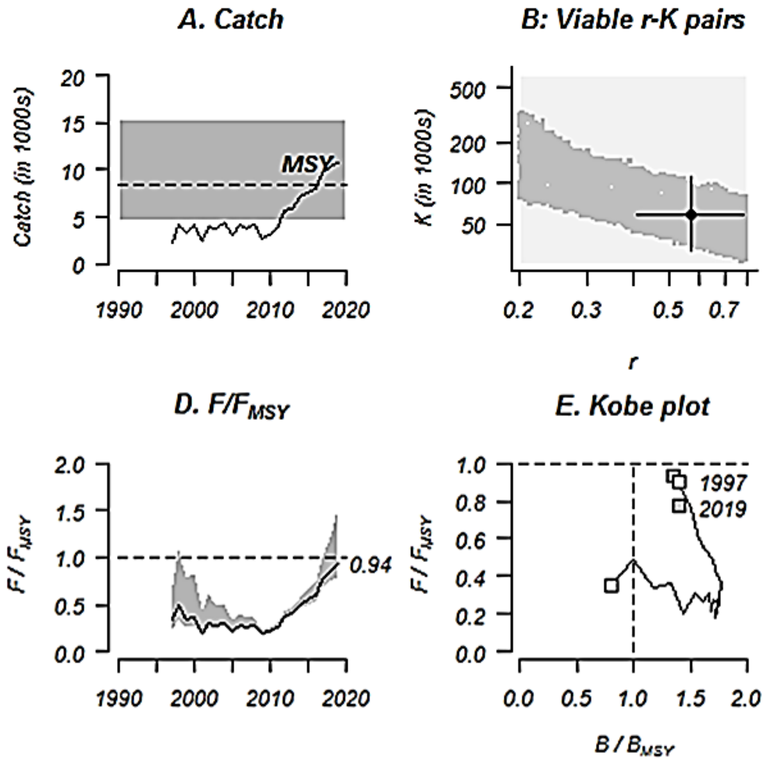

Figure 3. Changes trend of catch, MSY, r, K, F/ Fmsy and B/Bmsy Based on Monte Carlo simulation (CMSY Model) for Indo-Pacific king mackerel in the Oman Sea and Persian Gulf.

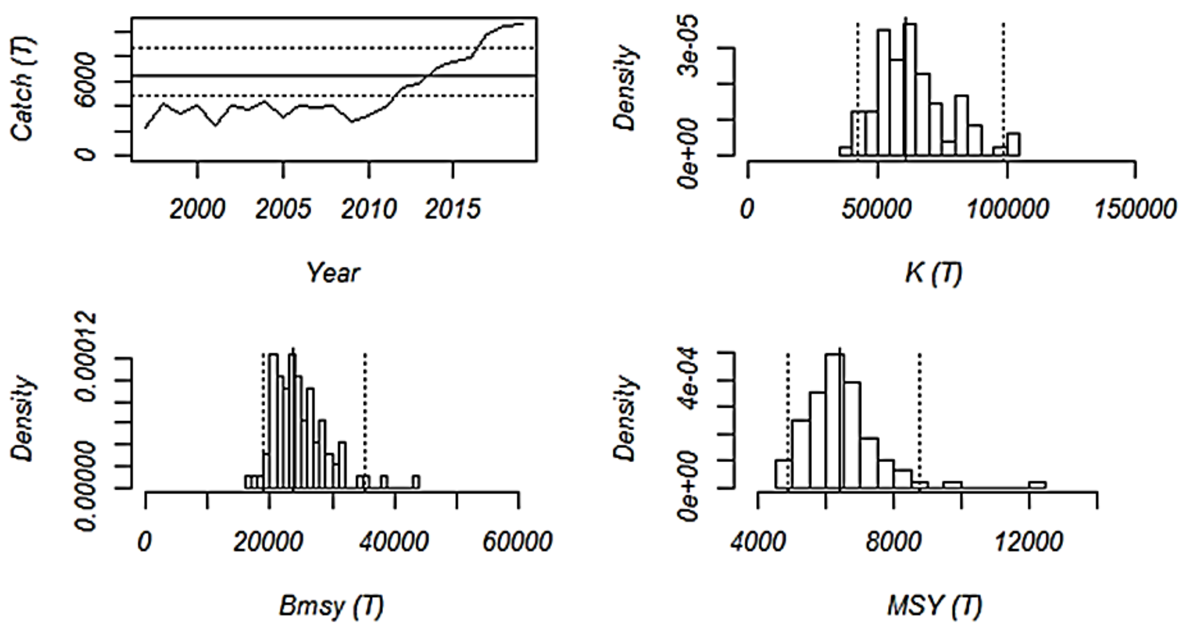

Figure 4. Changes trend of catch, MSY, K and Bmsy (DBSRA model) for Indo-Pacific king mackerel in the Oman Sea and Persian Gulf.

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 the 2019 year), respectively.

In DBSRA method, carrying capacity (K), MSY, the Bmsy, and current biomass (B) after 30000 Monte Carlo simulations based on thousand tons were obtained as 63.6 (38.70-104), 6.46 (4.62-12.40), and 20 (14.11-60) (in 2019), respectively (Fig. 4; Table 1). The biomass (B) to biomass of the maximum sustainable yield (Bmsy) ratio (B / Bmsy) in the CMSY model and *DBSRA* model were 1.36 and 0.8 (in 2019), respectively. The B / Bmsy and F / Fmsy ratios showed decreasing trend and an increasing trend, respectively. The average (95% confidence

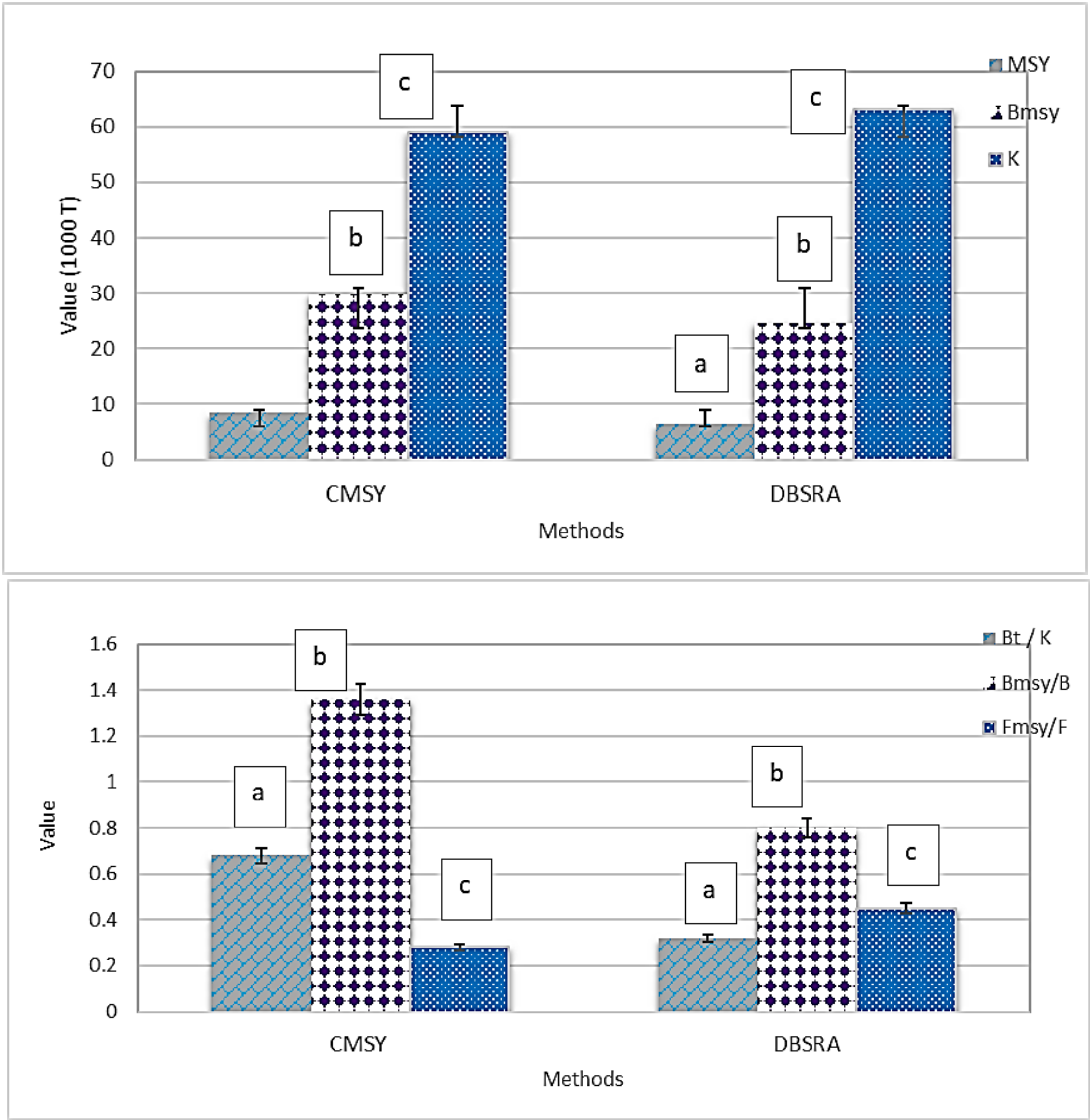

Figure 5. Changes mean of Fisheries Reference Points (FRP) in the CMSY and DBSRA models for Indo-Pacific king mackerel in the Oman Sea and Persian Gulf.

interval) biomass of the maximum sustainable yield (Bmsy), MSY as well as K in the two models showed were not significantly different (Fig. 5) with the one-sample t-test (P>0.05).

Discussions

Over the past two decades, the catch rates of the Indo-Pacific King mackerel in the southern waters of Iran had risen to more than 10,000 tonnes in 2019, indicating a sharp increase (Fisheries Statistical Yearbook, Iranian Area. 2020). 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). Hence, it is necessary to find the limits of this parameter (Froese and Pauly, 2015). The different species divided with the population instantaneous growth rate (r) values of 0.5-1.5 (high flexibility), 0.2-0.1 (moderate flexibility), 0.5-0.5 (low flexibility) and 0.1-0.015 (very low flexibility) (Froese et al., 2016; Martell and Froese., 2013). A significant relationship between this parameter (r) and other life-history parameters is present. The parameter r is approximately equal with 2 Fmsy, 2 natural mortality

(M), 3 Growth parameter (3 K), 3 divided by generation time (tgen), and 9 divided by maximum age (tmax) ($r \approx 2$ Fmsy $\approx 2M \approx 3K \approx 3$ / tgen ≈ 9 / tmax) (Froese and Pauly, 2015).

The Indo-Pacific king mackerel species status in the southern Iranian waters, based on B / Bmsy, is fully exploited and based on F / FMSY, which indicated near medium exploited (Arrizabalaga et al., 2012), and also recent catch is higher than its maximum catch. In Anderson et al. (2012) and Branch et al. (2011), the fishing situation is usually assessed based on B / Bmsy. It is divided into three parts, including the worth of B / Bmsy greater than or adequate to 1.5 (less than optimal fishing status), between 1.5 and 0.5 (full exploited status), and between 0.5 and 0.2 (overexploited status) and values Less than 0.2 (collapsed status).

One of the important indicators of Biological Reference Points (BRP) is the biomass of the maximum sustainable yield to carry capacity or stock status (Bmsy / K). This indicator in *S. guttatus* is shown to be near 0.5 (CMSY method) and 0.39 (DBSRA method), representing the Medium (0.2-0.6) depletion rate (Palomares and Froese, 2017). The optimal proportion of this ratio varies in different species and is usually 30-60%. Fish species with higher population intrinsic growth rates have less Bmsy / K (also vice versa). This index is considered 30-20%, and if less than this value indicates a sharp decrease in fish stock (Gabriel and Mace, 1999). Undoubtedly, the exploitation rate and population biomass change with population intrinsic growth rates (r) and Bmsy / K ratio (Zhou et al., 2016). The current study results show that the annual catch (about 10 thousand tonnes in 2019) exceeds the maximum sustainable yield (MSY) of *S. guttatus* in the South Waters of Iran, increasing its exploitation ratio and fishing effort not to be proposed. Stock status assessment for Indo-Pacific king mackerel in the Indian Ocean used catch-only methods techniques as Catch-MSY and OCOM in 2016. The yield target (MSY) was similar for both models considered (45,022, Catch-MSY, and 45,632 OCOM). The FMSY and BMSY (1000 t) for this species in the Indian Ocean have been reported to be 0.52 (0.40-0.69) and 66 (45.9-107), respectively (IOTC, 2020).

Several studies have shown no significant difference between the estimations of the CMSY and the Bayesian state-space surplus production (BSM) models, and some of them have been reported their 90% similarity (Froese et al., 2016) because of the initial input values of the population instantaneous growth rate (r) (Froese et al., 2016). Also, where CPUE was available rather than bio-mass, the indicated CMSY and BSM estimations of k, r, MSY, and k did not significantly distinguish 89% of the stocks (Palomares and Froese, 2017). Nowadays, many countries use Management Strategy Evaluation (MSE) and closed-loop simulations to assess the function of various management techniques for fisheries with few data (Harford and Carruthers, 2017). However, comparing the performance of data-limited fisheries procedures for estimating the stock status is crucial. The DB-SRA is inappropriate for the short-lived species i.e. $M > 0.2$ in each year (MacCall, 2009) and low-current level of bio-mass (Newman et al., 2014). In MSY-based management, it has been suggested the decreased margin of error of MSY (i.e., geometric mean MSY-2SD) must be applied as one of the targets for TAC under conditions when the size of a stock is > 0.5 k (Martell and Froese, 2013). Taken together, catch-based techniques are usually more biased for long-lived species.

Hence, it could be stated that Catch-MSY method with the estimated r can provide a good fitness for the fisheries in the Oman Sea and the Persian Gulf, which also presents one of the beneficial choices to evaluate the regional stocks in southern Iranian waters. Nevertheless, r estimation needs to be cautiously considered because fish's biological and ecological approach experienced some changes.

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