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Research Article

Estimation of fisheries reference points for Longtail tuna (*Thunnus tonggol*) in the Iranian southern waters (Persian Gulf and Oman Sea)

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Abstract

In the present research, the Catch-only method was used to determine the biological reference points (BRPs) of Longtail tuna (LOT) in Iranian southern waters (Persian Gulf and Oman Sea). Depletion-based stock reduction analysis (DBSRA) and Catch maximum sustainable yield (CMSY) models were used to estimate BRPs by applying data from 1997 to 2018.The B/B_{MSY} was calculated as smaller than 1.0 in both models, while F/F_{MSY} was mostly higher than 1.0, which indicates the overfishing of Longtail tuna in this area. In 2012, the F/F_{MSY} ratio has exceeded over 1.01 and the B/B_{MSY} ratio with 2 years delay was declined in 2014. Consequently, the biomass reduction followed in 2016, declined to the below of B_{MSY} and the fishing pressure was not adjusted to combat. In comparison, DBSRA model indicated more cautious than CMSY in BRPs estimation for LOT in Iranian southern waters. Based on BRPs, it is recommended to implement an adjustment of annual harvest (around 55 thousand tons) as the simple (even quick) fisheries management strategies in order to guarantee the sustainable yield of this species in southern waters of Iran. We also recommend that catch-only methods could be treated as a temporary stepping-stone while sufficient data (e.g. size or age composition) is available for more reliable methods to be applied.

Keywords: Longtail tuna, Biological reference point, Fisheries management, Persian Gulf and Oman Sea

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Introduction

Longtail tuna (*Thunnus tonggol*, Bleeker, 1851) (hereafter, LOT), ranked as the second smallest *Thunnus* species, is found throughout the tropical and subtropical in neritic waters of the Indo-Pacific region (Zischke *et al*., 2019; Griffiths *et al*., 2020; Sadough Niri *et al*., 2020). The geographic distribution of LOT tuna varies seasonally, extending from the northwestern Arabian Sea-including the Persian Gulf, Oman Sea and the Red Sea-and southward to the Maputo Province in southern Mozambique (Chacate and Mutombene, 2015). LOT supports commercial, artisanal and recreational fisheries throughout the world by almost 281,613 mt catch in 2017 (FAO, 2019). It is now the fifth most important species in Indian Ocean tuna fisheries with a catch of 133,931 mt in 2018, which comprise around 23% of neritic tuna catch in the Indian Ocean (IOTC, 2020). Compared to other *Thunnus* species, LOT occupies the neritic regime in depths of at least 90 m and occasionally appears far offshore in almost unique distribution (Yesaki, 1994; Griffiths, 2020). The lack of a swim bladder is a possible adaptation of LOT for living in shallow neritic waters of 17–30°C which heighten the hypothesis of vertical movements restriction to a depth of approximately 90 m (Griffiths, 2020; Griffiths *et al*., 2020). LOT is a gonochoristic species whose population has no specified sexual dimorphism in external morphology (Griffiths *et al.*, 2019). Fish spawning happens during the warmest period of the year over a period of several months at each region. Almost few studies have assessed the diet composition of this species. The earlier research indicates that LOT is an opportunistic predator consuming a variety of prey types (e.g. squids, crustaceans, cephalopods and teleosts) (Griffiths *et al*., 2020). Generally, LOT was caught by small-scale commercial and artisanal fisheries in at least 21 countries in the world (FAO, 2019), and dominantly contributed by Iran, Pakistan and India in the Indian Ocean using drift gillnets (Kaymaram *et al*., 2013; Moazzam and Nawaz, 2014; Darvishi *et al*., 2018; Griffiths *et al*., 2020). The dramatic increase in LOT tuna catches (due to increase in drift gillnet catches by Iran) followed from 25,000 to 81,000 MT between 2006 and 2011(IOTC, 2012) and dropped around 61,168 MT in 2018 (IOTC, 2020).

In the Indian Ocean tuna fishery, LOT tuna stocks have recently been assessed as being subject to overfishing (Abdussamad *et al*., 2012; Darvishi *et al*., 2018; Restiangsih and Hidayat, 2018). Conservation and management measures are not currently enough specifically for LOT to act against overfishing. Thus, LOT tuna stock has not been assessed properly due to a paucity of reliable biological information. Another issue is the lack of formal fisheries reference points for most commercially exploited fish stocks globally (Froese *et al*., 2012, 2016; Zhou *et al*., 2012). Moreover, the status of stocks and plan of action are

unknown. Consequently, fisheries' scientists have used data-limited catch-only assessment models that can produce highly uncertain estimates of stock status. There is a growing interest in applying data limited stock assessment methods, and new methods are developing very quickly. Zhou *et al.* (2017) introduced an optimized catch-only assessment method for data poor fisheries of 13 stocks in Australia, and concluded the method comparable with those from the full assessments. Forwardly, data limited methods were applied for assessing Indian Ocean neritic tuna species and were recommended as the preferred method for neritic tuna until sufficient data became available for applying data-rich traditional stock assessment (Zhou *et al.*, 2019). However, performance of catch only methods in estimating stock biomass is under criticism and more careful evaluation is recommended before it is considered as a reliable tool for stock management strategy (Free *et al.*, 2020).

Overall, reference points are suggested as a critical component of ecosystem-based fisheries management (EBFM) (Hall and Mainprize, 2004; Rice, 2009; Link, 2010), especially for the management of predator's fisheries or even specific purpose of fishery management (Hill *et al.*, 2020). Environmental variables could affect many fish species and especially tuna's distribution and living habitat by direct and indirect pathways (Lan *et al.*, 2018; Lee *et al.*, 2020; Vayghan *et al.*, 2020a; Vayghan., 2021), while changes in environmental condition can impact the productivity of forage stocks (Sydeman *et al.*, 2015). Thus, this leads to the "relative reference points" development, which changes over time to track environmental conditions (Hill, 2013). Nonetheless, the monitoring of the environmental effects on reference points through the ocean and marine ecosystem is quite complicated and time limited (Hill *et al.*, 2020).

The Regional Plan of Action on Neritic Tunas in South East Asia has focused little fundamental study regarding LOT stock structure, biology, movements, or extent of fishery exploitation in west Asia, especially in Gulf of Oman and Persian Gulf. Hence, based on the previous report on extremely exploited and overfished at a higher level than the optimum of LOT stocks (Darvishi *et al.*, 2018) and a better management policy and finally implementing regional EBFM in the waters of the northern Persian Gulf and Oman Sea, we conducted catch-only fisheries reference point research based on Iranian fishery data through the Iranian fishing port over the four provinces of the southern waters of Iran.

Materials and methods

Study area and fishery data

The study area covers four main Iranian fish landing (Khuzestan, Bushehr, Bandar Abbas and Chabahar) located in the northern Persian Gulf and Oman Sea waters (Fig. 1). The LOT fishery data were collected from the logbooks of Iranian drift gillnets fishing fleets

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(Dhows and boats) in the southern Iranian waters, which were supplied by the Iranian Fisheries Organization (IFO). Data from 1997 to 2018 were gathered for calculation and inputted into the model (Fig. 2). Due to the low share of catch (<0.2%) in Khuzestan Province, the relevant data was ignored in the calculation. Generally, nets are set in the evening and retrieved during the early morning (Moazzam and Nawaz, 2014).

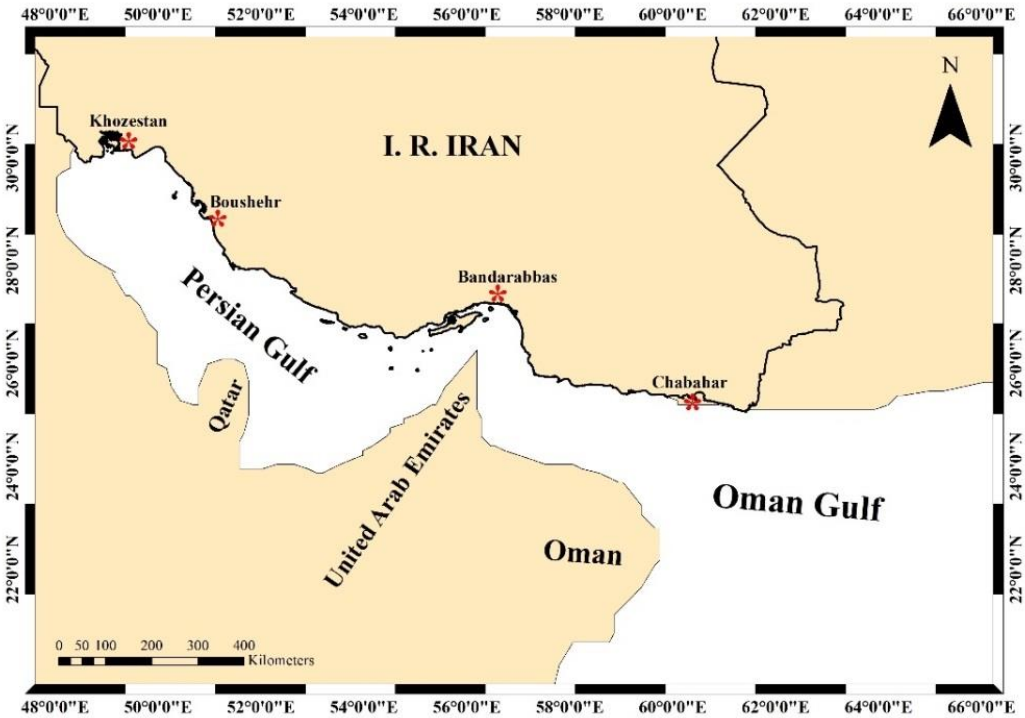


Figure 1: Map of the study area and main Iranian fishing ports (stars denote the fish landing location).

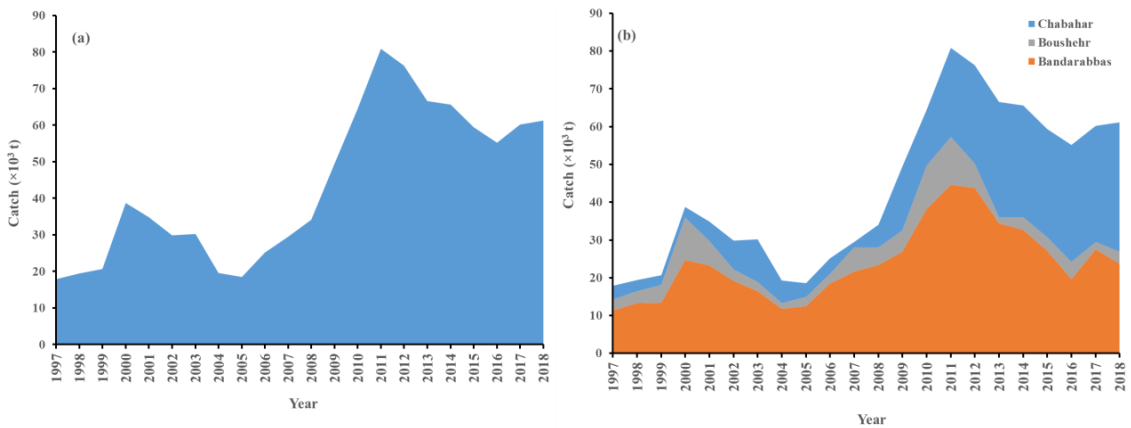


Figure 2: Long term fishing trends of longtail tuna catch in (a) overall Iranian waters, and (b) Iranian fishing ports.

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Model development and data analysis

Catch-only methods have been widely used in data limited stocks, where time series of catch records are available (Froese *et al*., 2017; Zhou *et al*., 2019). There are two interesting methods - catch maximum sustainable yield (CMSY) (Martell and Froese, 2013; Froese *et al*., 2017) and optimized catch-only method (OCOM) (Zhou *et al*., 2018)-than other catch-only methods trying to produce time series of biomass, fishing mortality, and both related fisheries reference points (BMSY, FMSY) based on catch history (Zhou *et al*., 2019). Both methods are designed based on the Graham-Schaefer surplus production model according to Equation 1, and rely on prior ranges of r and k and possible ranges of stock sizes in the first and final years of the time series (Martell and Froese, 2013).

$$B_{y+1} = By + rBy\left(\frac{1-By}{k}\right)e^{s^1} - Cy_{e^{s^2}} \quad (1)$$

Where B_{y+1} is the exploited biomass in the subsequent year *y+1*, *By* is the current biomass, C_y is the catch in year *y*, *r* and *k* are the population intrinsic growth rates and carrying capacity, respectively. The $e^{s1}$and e^{s2} are related to processing error and observation error, respectively. 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:

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

$$S = 1 - \frac{B_y}{k_y} \quad (3)$$

The maximum steady-state fishing mortality rate of maximum sustainable yield (F_{MSY}), the maximum sustainable yield (MSY) and Biomass of maximum sustainable yield (B_{MSY}) (Zhou *et al*., 2017) were calculated using following formula:

$$F_{msy} = \frac{r}{2} \quad (4)$$

$$MSY = \frac{rk}{4} \quad (5)$$

$$B_{msy} = \frac{k}{2} \quad (6)$$

A prior range for parameter r, according to classification of resilience in FishBase (Froese and Pauly, 2019) and proposed by Martell and Froese (2013) was set as 0.2– 0.8 for LOT since this species placed as medium resilience fish species.

Depletion-Based Stock Reduction Analysis (DBSRA) (Dick and MacCall, 2011) was also used to get an estimate of *MSY* and compare with CMSY method. In general, DBSRA estimates the carrying capacity (*K*) necessary to have sustained an observed time series of catch resulting in recent stock biomass levels. DBSRA utilizes a delay-difference reparameterization of the Pella-Tomlinson production model to characterize the changes in biomass and production.

$$B_t = B_{t-1} + P(B_{t-a}) - C_{t-1} \quad (7)$$

Where B_t is biomass at time t, B_{t-1} is biomass at t-1, P is the production of B_{t-a}, a is the median age of entry into the exploitable biomass, and C_{t-1} is the catch (harvest in weight) at time t-1. $P(B_{t-a})$ is calculated as:

$$P = g.MSY.\left(\frac{B_{t-a}}{K}\right) - g.MSY.\left(\frac{B_{t-a}}{K}\right)^n \quad (8)$$

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The parameter controlling the shape of the production curve (*n*) is associated with the leading parameter *BMSY/K* and is solved iteratively conditional on the B_{MSY}/K parameter. The parameter *g* is related to *n* and is derived after solving for *n*. *MSY* is calculated when *K* is solved (more information on Dick and MacCall, 2011).

The statistical analysis was performed using R package "Catch-MSY" and "DBSRA" in R studio (1.1.446) software, SPSS (version 26) also used for extra statistics. The significance level and confidence interval were 0.05 and 95%, respectively.

Results

According to the data, the trend of LOT catch increased from 2006 and dropped in 2011 in Iranian waters (Fig. 2). In 2018, the contribution of Iran catches to total Indian Ocean LOT was 45.7%. The main parameter of fisheries reference point for LOT, according to CMSY was estimated by the model and presented in Table 1. The model showed that the BRPs of B/B_{MSY} were mostly smaller than 1.0, while F/F_{MSY} was mostly higher than 1.0. This is an indication of the overfishing of LOT in Iranian waters (Fig. 3).

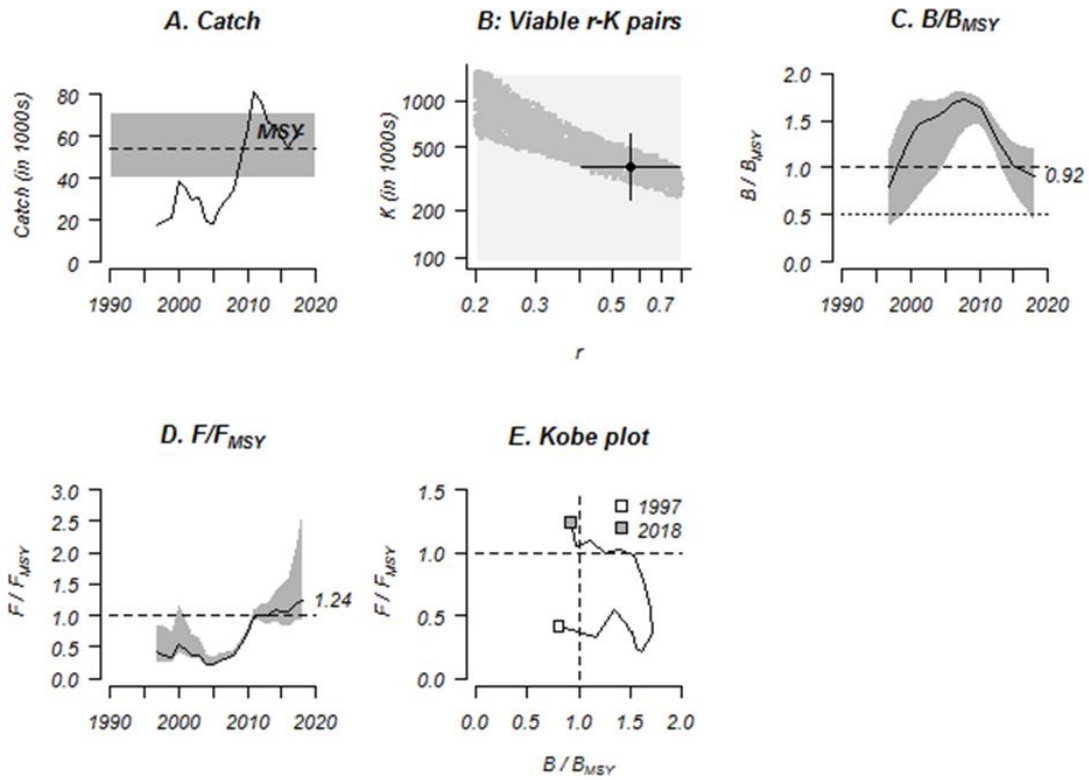


Figure 3: The results of CMSY model for LOT using total fishing data of main Iranian fish landing sites from 1997-2018.

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CMSY output of predicted total catch versus MSY graph indicated a sudden increase in total fishing (Fig. 4a) followed by a dropped in biomass in 2011 (Fig. 4b). In 2012, the F/F_{MSY} ratio exceeded to over 1.01 and the B/B_{MSY} ratio declined in 2014 with 2 years delay (Fig. 4c and d). Consequently, the biomass reduction followed in 2016 declined to the below of B_{MSY}. DBSRA model output for LOT using total fishing data of main Iranian fishing port from 1997-2018 is presented in Figure 5. The estimated DBSRA values close to CMSY for LOT fisheries reference point are presented in Table 1. However, some of fisheries reference point indicators were different (e.g. fishing mortality, F_{MSY} and B_{MSY}). F/F_{MSY} and biomass were mostly lower than CMSY method, while F_{MSY} estimated higher than CMSY method.

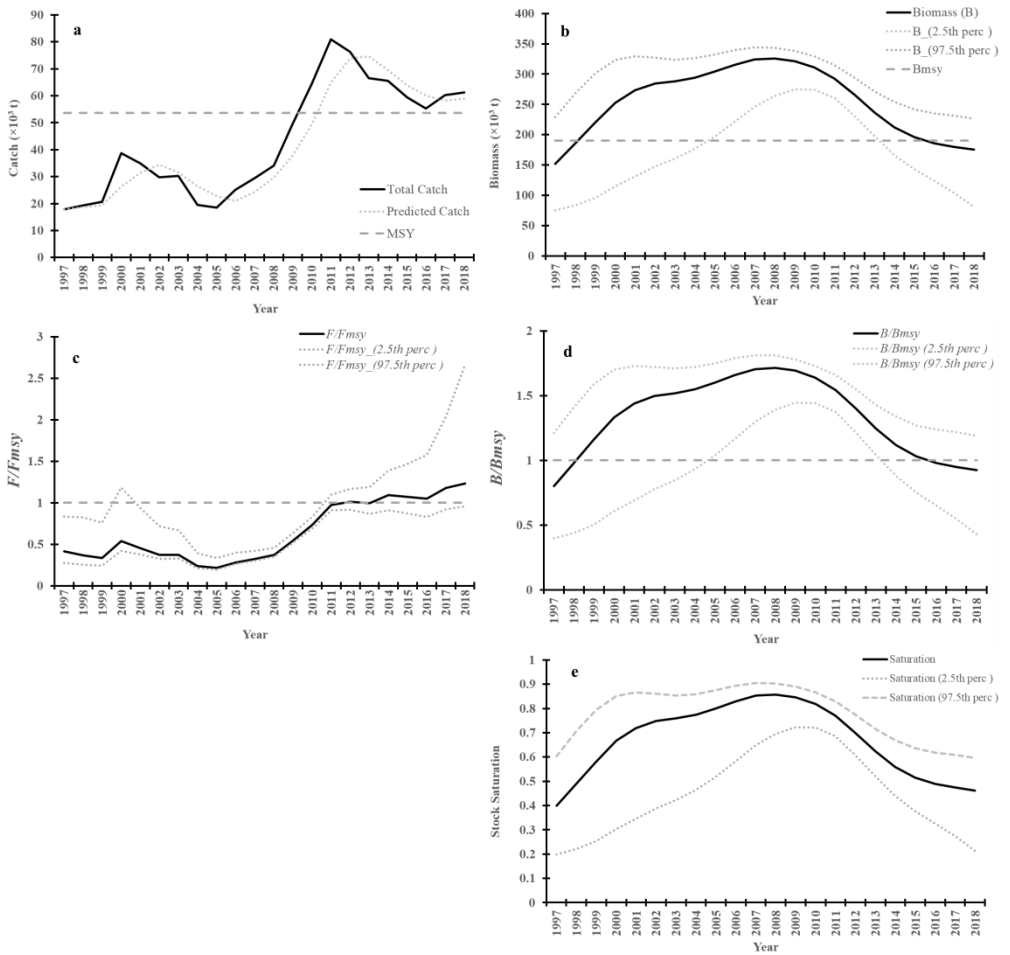


Figure 4: CMSY output of (a) observed total catch (bold curve), predicted total catch (dotted curve) versus MSY (dashed line), (b) biomass (bold curve) versus B_{MSY} (dashed line), with 2.5th and 97.5th percentiles (dotted curves) (c) F/F_{MSY} (bold curve) with 2.5th and 97.5th percentiles (dotted curves), (d) B/B_{MSY} (bold curve) with 2.5th and 97.5th percentiles (dotted curves) and (e) stock saturation (bold curve) with 2.5th and 97.5th percentiles (dotted curves) of LOT based on Iranian fishing data from 1997-2018.

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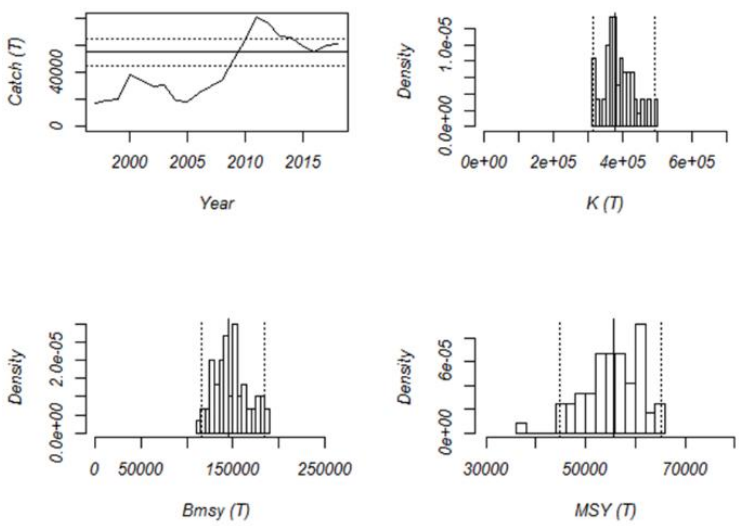


Figure 5: DBSRA model output for LOT using total fishing data of main Iranian fishing port from 1997-2018.

Table 1: CMSY and DBSRA as key prediction of fisheries reference point indicators for longtail tuna in Iranian southern waters (Persian Gulf and Oman Sea) (values in parenthesis represent 2.5th and 97.5th percentiles).

Parameter	Estimated values (Based on thousand MT)	
	CMSY	**DBSRA**
r	0.566 (0.407 - 0.785)	–
K	379 (235 – 611)	388 (314–489)
Biomass (*B)*	174 (80.5–226)	86 (33–164)
MSY	53.6 (40.1 - 71.8)	55.4 (44.9–65.1)
F_{MSY}	0.283 (0.204 - 0.392)	0.756 (0.347–1.28)
B_{MSY}	190 (118 – 305)	149 (116–184)
B/B_{MSY}	0.918 (0.425–1.19)	0.58 (0.29–0.89)
Fishing mortality (F)	0.352 (0.271–0.76)	0.747 (0.42–1.13)
B_{MSY}/K	0.501(0.502- 0.499)	0.385 (0.310–0.475)
Exploitation F/F_{MSY}	1.24 (0.957–2.69)	0.988 (0.88–1.21)
Relative biomass in last year	0.459 *k* (0.212–0.596)	–
Exploitation F/(r/2) in last year	1.24	–
OFL (overfishing limit)	–	32.3 (10.1–64.6)

Discussion

Reliable methods for estimating fisheries reference points such as that of maximum sustainable yield (MSY) and total allowable catch (TAC), especially in data limited fisheries, are necessary for any effective management of selected fish stock (Froese *et al*., 2017; Ji *et al*., 2019). Furthermore, the degree of stock depletion is vital for appropriate fisheries management as it is used for monitoring of management success and consequences. However, it is really challenging to estimate stock

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depletion in limited data stocks (Froese *et al*., 2017; Zhou *et al*., 2017). Though, there are some uncertainties about catch only methods that need to be taken into account for any specific decision (Carruthers *et al*., 2012; Pauly *et al*., 2013; Free *et al*., 2020), this method may present a useful alternative approach for data limited fish stock assessment (Zhou *et al*., 2018; Ji *et al*., 2019). In the present study, the BRPs of B/B_{MSY} based on CMSY method were estimated smaller than 1.0, while F/F_{MSY} was mostly higher than 1.0, indicating the overfishing of LOT in recent years. In 2012, the F/F_{MSY} ratio was exceeded to over 1.01 and the B/B_{MSY} ratio was declined in 2014 with 2 years delay. Consequently, the biomass reduction followed in 2016 fell below the B_{MSY} and the fishing pressure was not adjusted accordingly to reduce fishing pressure. Our finding regarding key BRPs was almost consistent with previous studies in the Indian Ocean (IOTC, 2016, 2020; Zhou *et al*., 2019), Persian Gulf and Oman Sea (Kaymaram *et al*., 2013; Darvishi *et al*., 2018). Ji *et al*. (2019) recommended more conservative management strategies for large head hairtail fishery, while F/F_{MSY} reached higher than 1.0 and B/B_{MSY} lower than 1.0. Hashemi *et al.* (2020) also indicated that overfishing in yellowfin tuna (*Thunnus albacares*) stock in the northern waters of the Oman Sea is happening. Therefore, specific measures should be taken to reduce catch and fishing effort. IOTC (2020) in recent report (by comparing two catch only methods) for LOT suggested that the exploitation rate (F/FMSY) has been increased over the last few years in the Indian Ocean, as a result of the declining abundance. This can be justified that perhaps an appropriate catch pressure balance was ignored in 2014 to support sustainable exploitation by the fisheries management. Furthermore, the stock status of LOT in Indian Ocean was studied by a few numbers of research (Zhou and Sharma, 2013; IOTC, 2017). This indicates that a tailored action is essential for LOT.

The population instantaneous growth rate (r) is one of the vital parameters in fisheries management for determining the population growth, and recoverable against the catch pressure (Zhou *et al*., 2016). One of the most important indicators of BRPs is the ratio of B_{MSY}/K, and this ratio was detected near 50% (or 0.501) for LOT, which confirms the medium (0.2-0.6) depletion rate (Palomares and Froese, 2017). Fish species with higher population intrinsic growth rates have fewer rates of B_{MSY}/K which show a sharp decrease in fish stock (Gabriel and Mace, 1999). The exploitation rate and population biomass could be affected by population intrinsic growth rates and consequently this would alter the rate of B_{MSY}/K ratio (Zhou *et al*., 2016). Hence, balancing of catch (as a primary decision by fisheries managers) can regulate the important indicators of BRP in stocks, where it faced overfishing such as that of LOT in southern waters of Iran.

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DBSRA is used for the management policy of stocks (Dick and MacCall, 2011) to derive an estimate of biomass (MSY) and abundance (F_{MSY}). Comparison of MSY estimated from the Catch-MSY (53.6 thousand MT), and DBSRA (55.4 thousand MT) models to historical landings showed that LOT landings in Iranian southern waters (Persian Gulf and Oman Sea) exceeded MSY during 2009-2011, but recently have been declined near to MSY in 2016 and not continued to below MSY. Using the results of F_{MSY} and B_{MSY} (as overfishing and overfished thresholds indicator) imply that overfishing is occurring. However, the population is not fully exploited or overfished status.

Unfortunately, the majority of global stocks remain unassessed (Costello *et al*., 2012) and present overly pessimistic views of global fisheries status (Branch *et al*., 2011; Anderson *et al*., 2012). Catch-MSY method (Froese *et al*., 2017) has been developed to estimate fisheries reference point, and recently has been applied for several data poor stocks of global (Costello *et al*., 2016) and regional fisheries (Froese *et al*., 2018), East China Sea stocks (Zhang *et al*., 2018), and Indian Ocean stocks (IOTC, 2016, 2017, 2020), among many others. The Catch-MSY method has been advanced as the optimized catch-only method (OCOM) because it uses an optimization algorithm rather than stochastic "thread the needle" approaches (Zhou *et al*., 2018). However, it is still categorized as a catch-only assessment method in stock assessment studies (Wetzel and Punt, 2015). Anyway, estimation of stock status is only the first step in the management process and status determinations alone do not guarantee or even preclude the effective and sustainable management of fisheries (Dowling *et al*., 2015). Consequently, successful management requires the testing and setting of harvest control rules, often facilitated by management strategies evaluation (Punt *et al*., 2016). Overall, sufficient knowledge of habitat characteristics of tunas (Lee *et al*., 2020; Vayghan *et al*., 2020a; Vayghan *et al*., 2020b) besides BRPs (Hill *et al*., 2020), is an effective way for implementing of EBFM on a global and regional scale.

This research determined the stock status of LOT in Iranian southern waters (Persian Gulf and Oman Sea) and recommended the adjustment of annual harvest (around 55 thousand MT) as the simple (even quick) fisheries management strategies, particularly for data poor stocks (Martell and Froese, 2013; Carruthers *et al*., 2014) to guarantee the sustainable yield of this species in Southern Waters of Iran. We also recommend that catch-only methods could be treated as a temporary stepping-stone while sufficient data (e.g. size or age composition) would be available for more reliable methods to be applied.

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