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Original Article

Stock assessment of Yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) using the LBB and LB-SPR methods in the northern Oman Sea, Iran

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Abstract: The current work aimed to develop a framework for the estimation of the optimized catch limit of the Yellowfin tuna (*YFT*), *Thunnus albacares* stock using catch data in the Iranian southern waters. In this study, two methods were employed to determine the biological reference points (BRPs) of this species. Biometry data was collected for 18 years (1993-2019) and the optimized catch limit was estimated using the limited data approaches. In an estimation method of Length-based Bayesian biomass (LBB), the highest length of this species was calculated as 166 (163-169) cm. The estimate of F/M = 1.9 (1.35-2.5) confirms the overfishing of yellowfin tuna, but the estimate of B/B_0=0.17 (0.109-0.238) shows the overfishing of the biomass. In an estimation method of length-based spawning potential ratio (LB-SPR), F/M>2.5 is upper the level that probably results in the maximum sustainable yield (F/M = 0.8-1.0). In the present study, the spawning potential level of the population was estimated at approximately 11%, which means over-exploitation of this species so far. The results showed that the exploitation ratio of *YFT* stock is overfishing (overexploitation) and a decrease in exploitation ratio and fishing effort are proposed. Regarding the condition of yellowfin tuna stock, both LBB and LBSPR methods confirmed each other and there is no big difference between them.

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Introduction

Fisheries management faces many challenges due to the scarcity or absence of data for stock assessment, particularly in developing countries. An estimation method of length-based spawning potential ratio (LB-SPR) is an empirical model described by Hordyk et al. (2015a). The LB-SPR is able to estimate fishing mortality to natural mortality (F/M) ratio and length selectivity, enabling the calculation of the reproductive potentials of a fished stock relative to an unfished stock. The SPR refers to the proportion of unfished reproductive potential retained at any level of fishing pressure (Hordyk et al., 2015b). This method is on the basis of equilibrium, considers fixed recruitment, and is unable to embrace a composition of multi-modal lengths, called Lee's phenomenon. Hence, there is a possibility of unrealistic estimates of selectivity, F/M ratio, and SPR.

Combining the size of fished populations has been previously applied in fisheries management for estimating the status of stock and fishing (Beverton and Holt, 1957), and calculating relative spawners' abundance and SPR (Hordyk et al., 2015b), as well as evaluating the role of age and size structure when comparing with a healthy stock (Froese et al., 2015). The LB-SPR is able to analyze the status of stock for fisheries with poor data (Hordyk et al., 2015a, b). The SPR is a common approach for stock assessment through the determination of target reference points (TRPs) and limits reference points (LRPs) in fisheries (Clark, 2013). According to the WCPFC, the unfished biomass of $SB_{F=0}$ is adopted as a reference point, and 20% $SB_{F=0}$ as a LRP (Rice and Harley, 2014) and 50% $SB_{F=0}$ as an interim TRP (WCPFC, 2014; Scott et al., 2020) for Yellowfin tuna, *Thunnus albacares* (YFT). Management objectives for a fishery closely associated with Target reference points (TRPs) (Scott et al., 2020).

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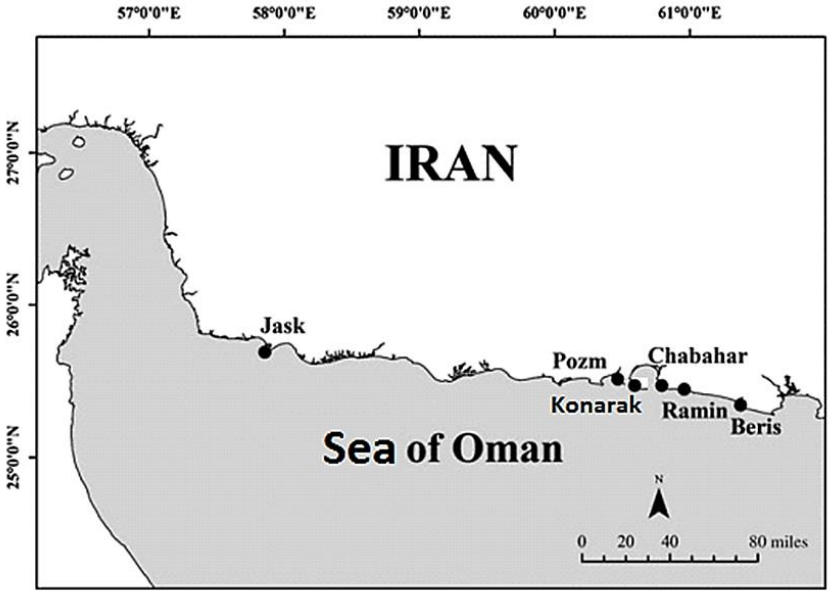

Figure 1. Sampling stations of Yellowfin tuna, *Thunnus albacares,* in the northern waters of the Oman Sea, Iran.

An estimation method of length-based Bayesian biomass (LBB) is a simple approach to analyzing the length frequency data related to various stocks. The LBB consists of numerous parameters whose synchronous estimation can improve fishery management and subsequently the livelihood of fishermen. The LBB could be a promising candidate for estimating both tropical and subtropical stocks, which are poor in terms of data (Froese et al., 2018). The LBB is an estimator for length-frequency (LF) data, in particular for those data obtained from the commercial fishery. This model is effective for species that grow throughout the entire lifetime, like most invertebrates and fish, and does not need any input other than length frequency (LF) data.

The LBB is able to determine the F/M ratio, relative natural mortality (M/K), asymptotic length (L_{inf}), and length at first capture (L_c) in the age range of the length-frequency sample. Regarding such indices as input, the ratio of current exploited biomass /unexploited biomass (B/B_0) can be estimated by the standard equations of fisheries (Froese et al., 2019; Yue et al., 2021). It should be mentioned that such indices make it possible to determine the L_c, which can increase maximally the catch and biomass for a desired fishing effort (*Lc_opt*), and to determine a representative for relative biomass denoting maximum sustainable yields (MSY) (B_{msy}/B_0). The relative biomass values estimated by LBB were almost the same as true values determined in simulated data and the same as independent values estimated from entire stock assessments. This is an updated version of the LBB code which (i) uses median maximum length across available years instead of absolute maximum length as the default start value for estimating a prior for L_{inf}, (ii) allows users to specify in the ID file whether they want to exert a correction for pile-up impact which may occur in species with continuous reproduction, and (iii) shows an LBB analysis for each year with data and stops execution if LFs in the examined year are unrealistic (Froese et al., 2019; Yue et al., 2021). The inputs needed for the LBB method are the length-frequency data, life cycle parameters, and length at first maturity (L50). The LBB model is used to determine the percentage of matures, relative fishing mortality (F), and relative natural mortality (M) as the average in the age range shown in the length-frequency data (Froese et al., 2018). Based on the above-mentioned background, the current work presents the LBB and LB-SPR methods for analyzing YFT, *Thunnus albacares* (Bonnaterre, 1788) in the northern waters of the Oman Sea.

Materials and Methods

Study area and fishery data: According to the statistics of commercial fish catch, data of YFT sampling monthly was obtained from the northern waters of the Oman Sea by selecting five landing areas (Fig. 1), including ports of Jask (57°77´E, 25°64´N), Konarak (60°28´E, 25°60´N), Pozm (60°28´E, 25°14´N), Ramin (60°45´E, 25°15´N) and Beris (61°10´E, 28°82´N). Biometric information (length frequency) between 1993 and 2019 was prepared by the Iranian Fisheries Organization (IFO) (IFO, 2020). Biometrics (length measurement) was conducted on over 26000 fish. A biometric ruler with an accuracy of 1 cm was applied to measure fork lengths.

Model development and data analysis

LBB estimator: The length-frequency (LF) data are utilized for stock assessment using the LBB estimator (Froese et al., 2018). The LBB is able to determine some indices using LF data such as L_{inf}, L_c, M/K, and F/M (Froese et al., 2018, 2019). Here, only basic and final equations have been reviewed, and details are according to Froese et al. (2018). The LBB assumes that the length growth follows the growth equation as suggested by Beverton and Holt (1957), as follows: $L_t = L_{inf}(1\text{-exp-}K(t-t_0))$. In this equation, Lt stands for length at t^{th} age, L_{inf} for asymptotic length, K for the rate at which L_{inf} reaches, and t_0 for theoretical age at length 0 (Froese et al., 2018). The width or length growth of YFT is in accordance with the growth equation of von Bertalanffy (1938) as proposed by Beverton and Holt (1957) as follows: $Wt = W_{inf}(1\text{-exp-}K(t-t_0))^b$, where, Wt stands for width at t^{th} age, W_{inf} for asymptotic length, K for rate in which W_{inf} reaches, t_0 for theoretical age at length 0, and $W\infty = a.\ L\infty^b$ where a and b stand for length-weight relationship (Froese et al., 2018).

With fully chosen by the gear for the fish, the catch curvature on the right side is a function of total mortality ($Z = M + F$) versus K, as follows: $NL = NL_{start}\ (L_{inf}–L/L_{inf}–L_{start})^{Z/K}$. In this equation, NL is survivor-to-L^{th}, NL_{start} for the count at length L_{start} with complete selection, meaning that all those who enter the gear are maintained by the gear, and Z/K for total mortality rate Z / somatic growth rate ratio.

The partial selection-influenced lengths, for each species, are a function of the fishing gear (here it is assumed that it is a trawl or other gear possessing a trawl-like selection curve), in accordance with Ogive described, as follows: $SL = 1/1+e^{-a(L-Lc)}$. In this equation, SL stands for the fraction of those kept by the gear at L^{th} length, and a for the slop of Ogive (Froese et al., 2018). The selection ogive indices can be determined simultaneously with L_{inf}, F/K, a, L_c, and M/K via fitting $Nli = NLi\text{-}1$. (L_{inf} –Li / L_{inf}–Li-1) M/K+F/K SLi; Cli = N Li . SLi, where, Li is the count of those at ith length, Li-1 for the count at earlier length, C for the count of gear-vulnerable ones, and all other above-mentioned indices (Froese et al., 2018). Finally, the stock assessment framework is described by the equation below based on L_{inf}, L_c, F/K and M/K (Froese *et al.*, 2016). According to M/K and L_{inf}, the L_{opt} which means the size with the largest cohort biomass is first calculated by the equation of $L_{opt} = L_{inf}$ (3 / 3 + M/K). Accordingly, and considering F/M ratio, the mean L_c value maximizing catch and biomass (Lc_opt) is calculated as follows: $Lc\_opt = L_{inf}$ (2+3F/M)/(1+F/M)(3+M/K). A proxy for relative biomass generating MSY is obtained by *the Lc_opt* estimates (Froese et al., 2018).

LB-SPR model: There is a need for several bio-factors related to YFT to estimate the LB-SPR, including L (asymptotic length calculated using the growth curve of von Bertalannfy), M/K (M = instantaneous natural mortality rate and K = the growth coefficient of von Bertalannfy), L_{95} (lengths at 95% maturity) and L_{50} (lengths at 50% maturity).

Data were analyzed by R (R Development Core Team, 2022) package “LBB” (Froese et al., 2018), LB-SPR R package (Carruthers and Hordyk, 2018), Rstudio (2023.03.1-446), R (4.3.0) software, and SPSS (26), and the significance level and confidence interval was 0.05 and 95%, respectively.

Results

The findings from the LBB model regarding YFT in the southern waters of Iran are given based on one species and in general terms, individually.

LBB method: *Thunnus albacares* grows in the Oman Sea and the Pacific and Indian Oceans, with the largest length of 166 cm (between 163 and 169 cm), which is

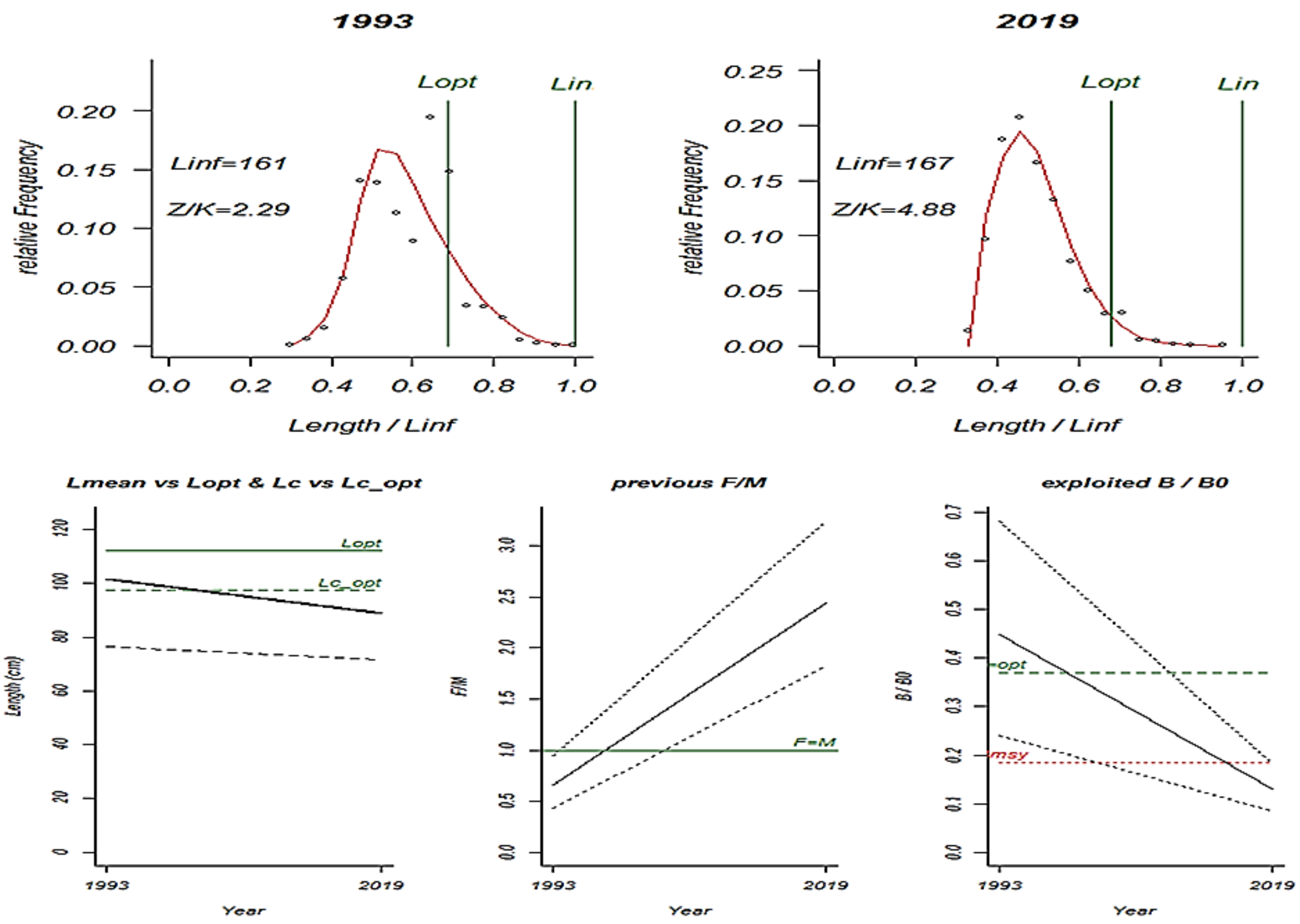

Figure 2. Changes trend of *Lopt*, *Lc-opt*, *F/M* and exploited *B/B0* Based on LBB method for *Thunnus albacares* in the Oman Sea.

Table 1. Comparison of different indices of LBB and LBSPR models for *Thunnus albacares* in the Oman Sea.

Scientist name (Year, Method)	*Lmean/Lopt*	*Lc/Lc_opt*	*L95th/Linf*	*B/B0*	*B/BMSY*	*F/M*	*F/K*	*Z/K*	Assessment
Yellowfin tuna (2019, LBB)	0.75	0.68	0.96	0.17 (0.109-0.238)	0.45 (0.296-0.646)	1.9 (1.35-2.5)	2.7 (2.34-3.1)	4.19 (3.91-4.43)	Overfished
Scientist name (Year, Method)	**SL50**		**SL95**		**F/M**		**SPR**		**Assessment**
Yellowfin tuna (2019, LBSPR)	65.5 (65.2-65.8)		75.8 (75.2-76.3)		2.64(2.58-2.78)		0.11 (0.09-0.11)		Overfished

a commercially precious species in these areas. The estimate of *F/M* = 1.9 (1.35-2.5) confirms the overfishing of yellowfin tuna, and the estimate of B/B_0 = 0.17 (0.109-0.238) also emphasizes the overfishing of the biomass of this species (Fig. 2). According to $L95/L_{inf}$ = 0.96, large species must be very rare to be absent, which is confirmed by *Lc/Lc_opt* ratio (0.68) and Lmean/Lopt ratio (0.75). The below unity of both ratios indicates the short-length structure and small fish catch.

LB-SPR model: Last year biometrics measures were used to estimate the parameters of life history. Table 1 shows the assessments of life history ratios for species examined. Sizes at 50 and 95% maturity were considered as 85 and 90 cm, respectively. The YFT asymptotic growth averages the highest size of 65 cm according to the Lm/L∞ value of 0.51 (Table 1) and the L_{50} value of 65 cm. Currently, relative fished pressure is *F/M*>2.5 even upper the level that probably results in the maximum sustainable yield (*F/M* = 0.8–1.0). The spawning potential level of the population is estimated at approximately 11%, which means over-exploitation of this species.

The specific estimated parameters SL50, SL95,

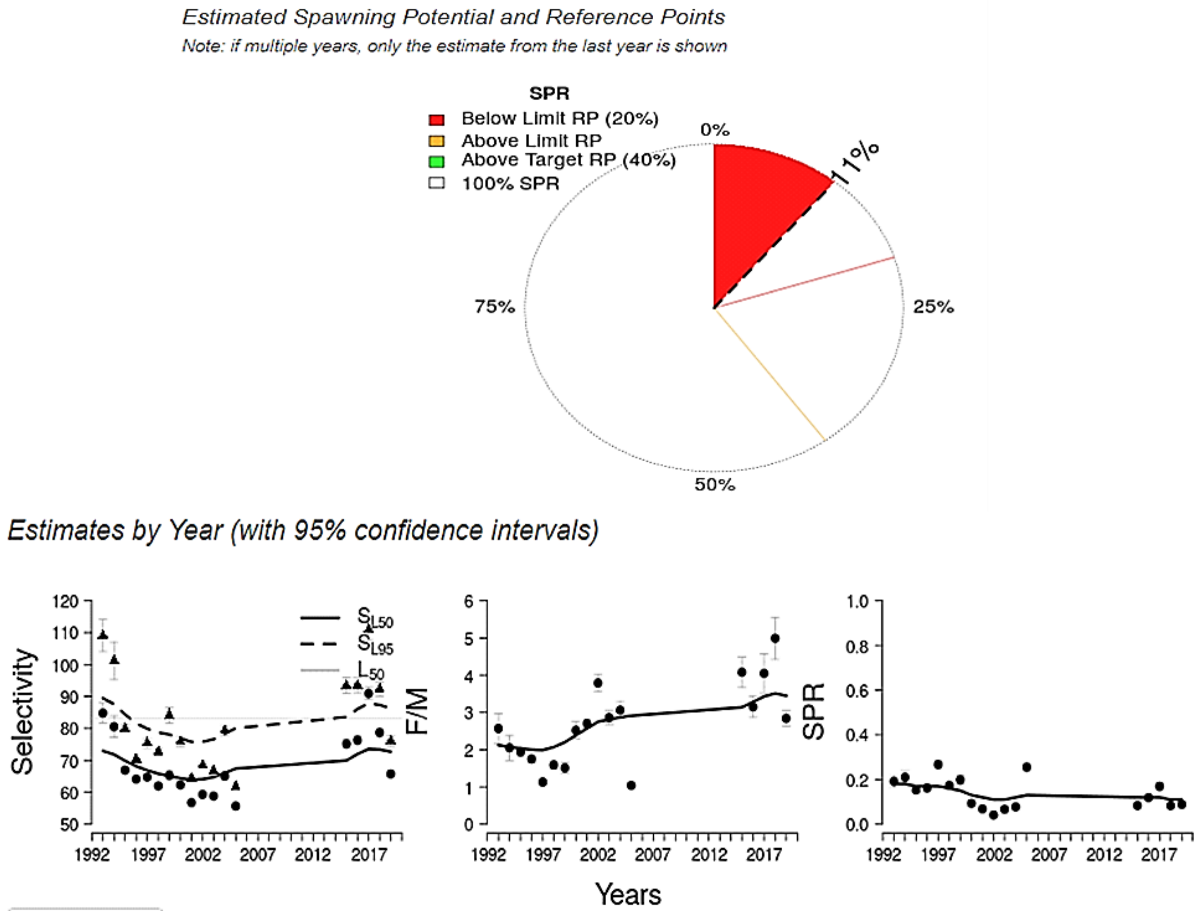

Figure 3. Changes trend of SPR, F/M, Selectivity (LBSPR model) for *Thunnus albacares* in the Oman Sea.

F/M ratio, and SPR by year are presented in Figure 3. According to 95% confidence intervals (95%CI) regarding SPR estimates, the estimates of relative fishing pressure and selectivity are presented below. Most SPR values were estimated in different years to be below 0.40 which is the proxy for B_{MSY}. This population might be experiencing overfishing.

Discussions

LBB approaches: The relative size of stock can be estimated by a facile and rapid method of LBB. Unlike other cohesive methods, this model does not require information on maturity, age, recruitment, effort, growth, or mortality, and only LF data obtained from commercial fishing is sufficient. LBB extracts priorities for L_{inf} and selectivity from accumulated annual LF samples, and the previous *M/K* ratio is assumed to be around 1.5 (95% CI = 1.2–1.8). Then, the LBB undertakes Bayesian analyses of the annual data of LF for simultaneous estimation of L_{inf}, *F/K, M/K,* and *Lc*. Based on such inputs, the combined equations of standard fisheries (Beverton and Holt, 1957) make it possible to determine relative biomass (*B*/*B*msy or *B*/*B*0) for the range of fished size.

The small value of the *Lc/Lc_opt* ratio and *Lmean/Lopt* ratio in the studied species indicates a short-length structure and small fish catch (Hashemi et al., 2020, 2021; Hashemi and *Doustdar*, 2022). The 95th percentile length-to-asymptotic length ratio in five stocks was *L95th/*L_{inf} = >0.9 meaning the presence of little larger fish. The B/B_0 ratio smaller than $BMSY/B_0$ in all stocks indicates the overfishing of the studied fish species. Moreover, the mean B/B_0 ratio was 0.16, which means an 84% depletion rate.

The relative biomass values estimated by LBB were almost the same as values determined in simulated data and the same as independent values estimated from entire stock assessments. LBB is known as a new marker to evaluate the role of an observed size structure as representative of a healthy stock. The results of LBB can obviously be misinterpreted in the case of inadequate data of length frequency to show the size composition of the stock fished size range, or due to the interaction of growth and mortality covered by potent recruitment pulses (Froese et al., 2018, 2019). According to the LBB, the fluctuations in recruitment, death, and growth are assumed to be around the average amounts in the age range in the LF (length frequency) specimen, and must not be applied in the case of violation of this assumption. For instance, the large variability of interannual recruitment can give numerous peaks and unacceptable analytical outcomes (Hordyk et al., 2015a).

LBB may exert a direct impact on the management of stocks with poor data i.e. missing or invalid catch data. LF representative specimens from the major gear applied in the fishery or the major landing location may be sufficient to obtain an initial idea of the size of the stock relative to the levels generating MSY. The LBB compares the current *Lc* relative to *Lc_opt*, which can give the highest catch and biomass for fishing pressure (Froese et al., 2016). Accordingly, the management may make changes in *Lc* values and fishing efforts as long as the relative biomass predicted by the LF data exceeds the approximate value of MSY.

The estimations of LBB can be effective as objective priors of relative biomass for application in other models of assessment. The estimations of LBB for *Lc* values and relative biomass when compared to corresponding reference points can have a direct application in management. Based on our findings, the LBB is suggested to be added as a new option to the toolbox of assessment, in particular for stocks with poor data. One of the convenient and easy indicators to estimate for the composition of age and size is theoretically the average length in the exploited populations relative to the length of the maximum biomass in the non-fishery population (*Lmean/Lopt*), which indicates a healthy stock. It must be regarded as a novel potent marker in assessing age and size structure.

LB-SPR models: The LBSPR rate of this species was 0.11 (%11) and has been on a downward trend in recent decades. The LB-SPR can offer SPR estimates so that the amounts less than 0.2 (about 0.5 *B/Bmsy*) mean the depletion and the amounts higher than 0.4 (about 1.0 *B/Bmsy*) mean an acceptable status of stock. In addition, 95%CI from LB-SPR shows unrealistic narrowing, and even near to definitive, thereby justifying their low fit score to some extent. Fisheries management has always sought to minimize the fishing effect on the age and size structure of populations exploited (Froese et al., 2016). Unrestricted fishing further decreases biomass, in particular, the application of greater M-values and consequently F-values for pre-recruitment (Froese et al., 2015). Management measures can be made for fisheries from length-frequency-based parameters (Froese, 2004; Froese et al., 2016). There are not many studies based on this theory, and its accuracy needs to be verified by more research results; the consequence drawn from this will be more convictive and acceptable when combined and compared with similar approaches (Yue et al., 2021).

LBB in comparison with LB-SPR*:* The SPR is a method similar to the LBB, which applies a part of the length-frequency curve higher than the length of *Lm50*, in which 50% are adults and computes the production of eggs via the length-to-fecundity conversion exploiting the length-to-fecundity relationship, and subsequently compares the production of egg with an egg that exists without fishing. In a study by Hordyk et al. (2015a, b, 2016) using the LB-SPR method, the results revealed that the estimation of SPR is carried out via Lc/L_{inf}, *M/K*, Lm/L_{inf}, and *F/M* ratios by assuming knife-edge maturation at *Lm* and knife-edge selectivity at *Lc* length. *M/K*, CVL_{inf}, *Lm95*, *Lm50,* and L_{inf} are the inputs needed for the model. Like the LBB, the average *F/M* ratio in the age range will be in the frequency-length specimen analyzed (Hordyk et al., 2015a, b). Unlike LB-SPR, there is no need for maturation programs or length-fecundity factors to recognize LBB. This deals with the knife-edge assumption problem and uses the existing data for the estimation of *M/K*, CVL_{inf}, and L_{inf}.

Hordyk et al. (2019) reported problems with LBB results, including the alteration of the *M/K* ratio value in accordance with the exploited species i.e. a misinterpretation of this ratio can affect the results. In a study by Froese et al. (2019), the LBB model was considered based on existing length data. Froese et al. (2018) introduced their model as an LBB estimator capable of decreasing the need for data for basic stock assessments. According to the LBB model, the largest size can be achieved at the highest age in a majority of tropical and subtropical species, indicating aligned natural mortality and somatic growth of adults with being reported in a fixed ratio (Froese et al., 2018). The suitability of the LBB method is better in species inhabiting tropical regions with rapid growth (Baldé et al., 2019) and growth-dependent nature of mortality (Z/K) for example West Africa (Froese et al., 2018). Hordyk et al. (2018) reported the sensitivity of LBB results because of assumptions regarding L_{inf}, and exploitation rate overestimation due to unrealistic L_{inf}.

Conclusions

The present study showed that Yellowfin tuna, *T. albacares* (YFT) did not have desirable stock conditions, and its stocks have reached 'overfished' status. Regarding the condition of yellowfin tuna stock, both LBB and LBSPR methods confirmed each other and there is no big difference between them. According to the terms and conditions assessed, and considering the sustainable fishing requirements, it is possible and recommended to decrease the catch of this species in the northern part of the Oman Sea along the coast of Iran.

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