Population dynamic parameters of Longtail tuna (*Thunnus tonggol*) in the Northern of the Persian Gulf and Oman Sea

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Length frequency data of longtail tuna was collected from April 2015 to March 2016. This study provides population parameters of this species in the Persian Gulf and Oman Sea. A total monthly data of 4383 individuals ranging from 25 to 124 cm fork length were analyzed with FiSAT II software using the ELEFAN1 package to estimate the population parameters. The length-weight relationship was $TW= 0.00002FL^{2.87}$ (R^2=0.97) showing an Isometric growth for *T. tonggol*. Growth parameters were computed $L\infty$ =129.6 cm, K=0.39 year^{-1} and $t_0 = -0.28$ with the growth performance index, φ' of 8.7. The total mortality (Z) was estimated 1.58 year^{-1} using catch curve method. The natural (M) and fishing mortality (F) were obtained 0.49 year^{-1} and 1.09 respectively. The exploitation ratio was 0.69. Length at first capture (Lc) was estimated as 60.2 cm fork length.

The yield per recruit (Y/R) maximized in maximum fishing mortality rate 0.85 year^{-1}. The biomass per recruit decreased to 17.2% of unexploited biomass (Virgin biomass) at F.

The current fishing mortality exceeds optimum fishing mortality (F_{opt}) and limit fishing mortality (F_{limit}). The results indicated that fishing effort should be reduced to prevent stock overexploitation in the Persian Gulf and Oman Sea.

Key words: *Thunnus tonggol*, Longtail tuna, Population dynamics, Persian Gulf, Oman Sea

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Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is fairly challenging due to the lack of available data (IOTC, 2015). The family Scombridae, mackerels and tunas, includes 15 genera with 49 species that form the basis for some of the world's most important commercial fisheries (Randall, 1995). Five species of neritic tuna were recorded as commercial fisheries from in the Persian Gulf and Oman Sea: Namely *Auxix thazard, Euthynnus affinis, Scomberomorus commerson, S. guttattus, and T. tonggol.*

In recently years (2006–2015) scombridae represented an average 39% of the total catch in the Persian Gulf and Oman Sea (Iranian waters). Scombrids are usually caught by surface gillnets (93%) and purse seine (5%) during their migration for feeding and reproduction to the Persian Gulf & Oman Sea. Longtail tuna *(Thunnus tonggol*) is an epipelagic species inhabiting in tropical to temperate regions of the Indo-Pacific, found almost exclusively in the neritic waters close to the shore, avoiding estuaries, turbid wasters and open ocean (Froese and Pauly, 2015). It is one of the smallest species of the genus *Thunnus*, but relatively large compared with other neritic species with a maximum length of 145cm (Pierre *et al*., 2014). Estimated global catches of longtail tuna increased gradually from the mid 1950's to the year 2000 when over 90,000 t were landed. Catches then declined until 2005 (67,600 t). Since 2005, catch have been increased continually with the highest catches ever recorded at around 170,000 t, landed in 2014. Over the past decade Thailand, Indonesia, Malaysia and Iran contributed most to the global landings. However, it is important to note that catch statistics are underestimates due to a high incidence of underreporting of longtail catches in underdeveloped countries, especially where the species is targeted in artisanal fisheries (Griffiths, 2010). Scombrids account for about 40% of the total catch in Hormuzgan province (in South of Iran) and *Thunnus tonggol* represent the major volume of this province fishery and its management depends on the provision of described information on population assessment.

It seems the distribution of the longtail tuna in the Persian Gulf and Oman Sea is associated with temperature of Sea surface water. In Iran, longtail tuna are targeted by traditional fishery, operating gillnets in small boats (fiberglass 6–8 m), or large dhows (less than 30 m wooden or fiberglass) and few industrial purse-seiners. However, this species is considered as one of the most important economic resources in Indian Ocean, very little new information is known about the dynamic population of *T. tonggol* from this area. (IOTC, 2015).

Some results of studies on population dynamics of longtail tuna in the Indian and Pacific Oceans reviewed by Kaymaram *et al.* (2013), Abdussamad *et al.* (2012), Griffiths *et al.* (2011), Froese and Pauly (2007), Ioth *et al*. (1999), James *et al.* (1993), Yesaki (1989) and Prabhakar and Dudley (1989).

The purpose of this study is to determine some important population parameters of *T. tonggol* such as growth, mortality and yield per recruit based on biological reference

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points in Iranian fisheries to provide information on population dynamic needed for fisheries management in the Persian Gulf and Oman Sea.

Materials and methods

Monthly length and weight frequency distributions were constructed to obtain growth curves and length-weight relationship. Samples were collected from five commercial landings along the Hormuzgan Coastal Waters called Jask, Sirik, Bandar Abbas, Kong and Parsian from April 2015 to March 2016 (Fig.1). The specimens were caught by vessels (boat and dhow) and each time, a random sample was taken before the catch was landed.

Fork length (FL) measured to the nearest 1 cm and pooled into 3 cm length classes and total weight (TW) to the nearest 0.01 kg. The length frequency data smoothed in order to decrease sampling error. The length-weight relationship was calculated by applying a power regression: $TW = aFL^b$. In this equation, length is independent variable. The parameter "a" is called the condition factor, and "b" usually designated the allometry coefficient, assumes values around three for isometric growth pattern. Student's t-test was used to compare the parameters obtained from general coefficient.

Growth parameters $L\infty$ and K were estimated by model progression analysis using the program ELEFAN1 (Pauly, 1987) within the FiSAT II program (Gayanilo *et al.,* 1994).Growth equation in length as a function of age (Von Bertalanffy) was:
$Lt=L\infty\ [(1-\exp(-K\ (t-t0))]$ where: $L\infty$=asymptotic fork length (extreme length), K= growth rate and t_0= theoretical age of fish at zero length. Extreme length estimated by maximum length estimation in FiSAT II software with 95% confidence. With this $L\infty$ value, Shepherd´s method was used t_0 estimate the K value (Shepherd, 1987). The theoretical age, at which the fish has mean length zero (t_0) was estimated by Pauly's (1979) formula: $\text{Log}(-t_0) = -0.392 – 0.275\text{Log}(L\infty) - 1.038\ \text{Log}(K)$

The index of growth performance (Pauly and Munro, 1984) was calculated using the equation: $\varphi= \text{Ln}(K) +2\text{Ln}(L\infty)$ ($L\infty$ and K are the growth parameters of the Von Bertalanffy equation). The index was compared with estimates obtained by other authors to facilitate the intra and interspecific comparison of the growth performance (Pauly and Munro, 1984).

Total mortality rate (Z) was estimated by the linearized length-converted catch curve: $\text{Ln}(N_i/dt_i) = a + Zt_i$, where: N_i is the number of fish in length class i; dt_i is the time needed for the fish to grow through length class i; t is the relative age where midlength is reached in class i (Gayanilo *et al*., 1995).

The natural mortality was estimated using the Pauly's (1980) empirical formula (as *T. tonggol)* are school migratory species multiplied 0.8 (Pauly, 1980)):
$\text{Log}_e(M) = -0.0152 -0.279\ \text{Log}_e(L\infty) + 0.6543\ \text{Log}_e(K) + 0.463\ \text{Log}_e(T)$

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Where: T is the annual mean water temperature value (The mean surface temperature of the Persian Gulf and Oman Sea was 27°C during the sampling). The current instantaneous fishing mortality rate (Fcurr) was estimated from the difference between the total mortality and the natural mortality: F_{curr}=Z-M, and the exploitation rate (E) was assumed to be E = F/Z (Sparre and Venema, 1992).

In order to determine of mean size at first capture ($L_C=L_{50\%}$), the probability of capture estimated by backwards extrapolation of the descending limb of the catch curve to include younger age classes that were likely to be underrepresented in the catch, within the FiSAT II program (Gayanillo and Pauly, 1997).

The Beverton-Holt model used to calculate yield per recruit curves (Y/R) and biomass per recruit (B/R) following the formulas (Beverton and Holt, 1957) using the Knife-edge selection:

$$Y/R = \frac{F}{K} \times A \times W\infty \times \left[\frac{1}{Z} - \frac{3U}{Z+1} + \frac{3U^2}{Z+2} - \frac{U^3}{Z+3} \right]$$

B/R=(Y/R) × (1/F)

Where:

$$A = \left[\frac{L\infty - Lc}{L\infty - Lr} \right]^{M/K}$$

(Lr =38.6 cm) (Abdussamad et al., 2014)

$$U = 1 - \frac{Lc}{L\infty}$$

(U=1- L_C / L∞ the fraction of growth to be completed after entry into the exploited phase)

The resource status was evaluated using estimates of fishing mortality rate associated with a maximum sustainable yield (F_{max}) and by comparing estimates of the current fishing mortality rate (Fcurr). A number of biological reference points estimated: 1) Fmax defined as the fishing mortality that produces maximum yield-per-recruit 2) F_{opt} =M/2 and 3) Flimit =2M/3 (Patterson, 1992).

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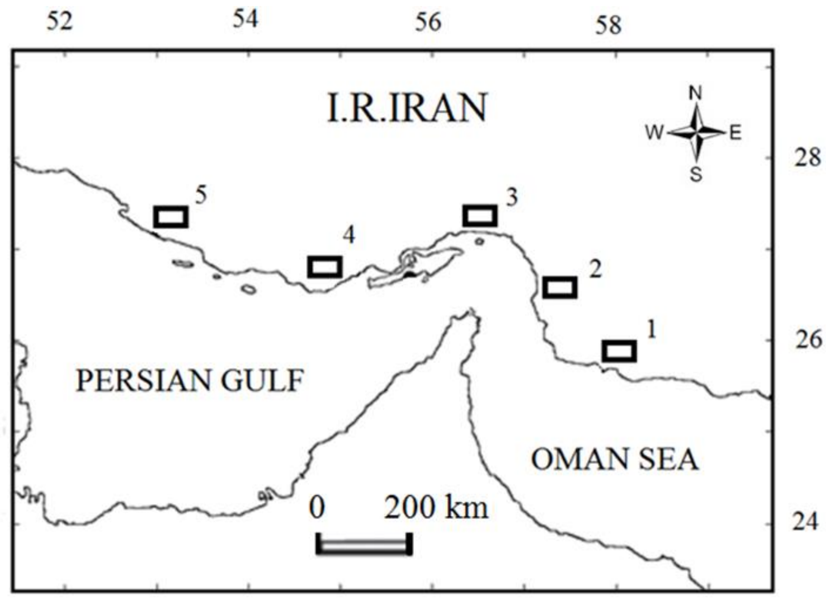

Fig.1. Sampling area of longtail tuna in Northern of the Persian Gulf and Oman Sea (2015-2016)

Results

Among the 4383 specimens of *T. tonggol* collected during sampling, dominant was from 25 to 124 cm FL with mean 71 (Fig.2).The weight and length pairs data of 331 longtail tuna were obtained and length-weight relationship was:

$TW=0.00002FL^{2.87}$ ($R^2=0.97$) (Fig.3). The computed growth coefficient (b=2.87) was not statistically different from 3 (t-test, P>0.05). The Von Bertalanffy growth parameters obtained for this species were $L\infty=129.6$ cm, K =0.39 year $^{-1}$ and $t_0= -0.28$ (Fig.4), which showed this species length attained at the end of 1, 2, 3,4 and 5 th year are found to be 50.9, 76.4, 93.6 105.2 and 113.1 cm respectively (Fig.5). The growth performance index (φ) was 8.7.

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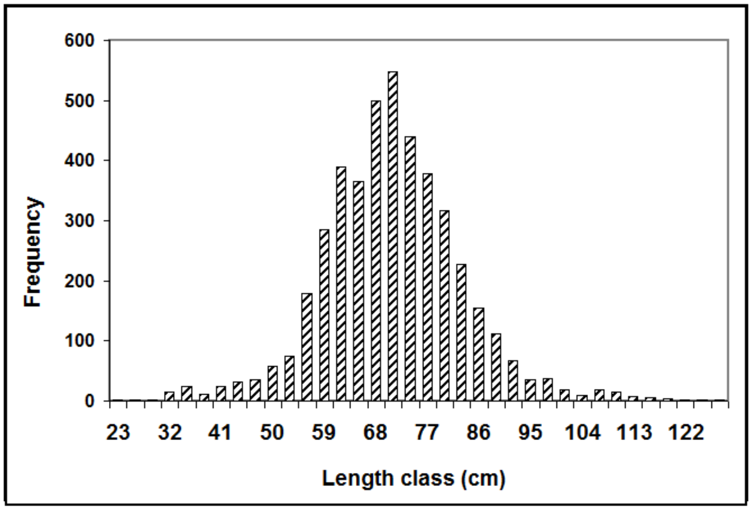

Fig.2. Length frequency distribution of longtail tuna in Northern of the Persian Gulf and Oman Sea (2015-2016)

The length-converted catch curve is shown in figure 6. The estimated instantaneous rate of mortality (Z) for *T. tonggol* was 1.58 year^{-1} (with 95% confidence interval of slope -1.707 - -1.454). Natural mortality and fishing mortality were estimated 0.49 year^{-1} and 1.09 respectively and exploitation rate was 0.69. The probability of capture curve (Fig.7) showed that the fork length of *T. tonggol* to be attained in 60.2 cm where the probability was 50%.

The yield per recruit (Y/R) and biomass per recruit (B/R) analysis were computed using the knife-edge procedure and maximum of fishing mortality rate (F_{max}) was 0.85 (Fig. 8).

In fact, Y/R increases steadily until the fishing mortality rate reach 0.85 year^{-1} and then decline with increasing fishing mortality. The biomass per recruit was 22.3% of unexploited biomass (Virgin biomass) at F_{max} point and decrease to 17.2% in current fishing mortality rate. The biological reference points were estimated and are shown in Table 1.

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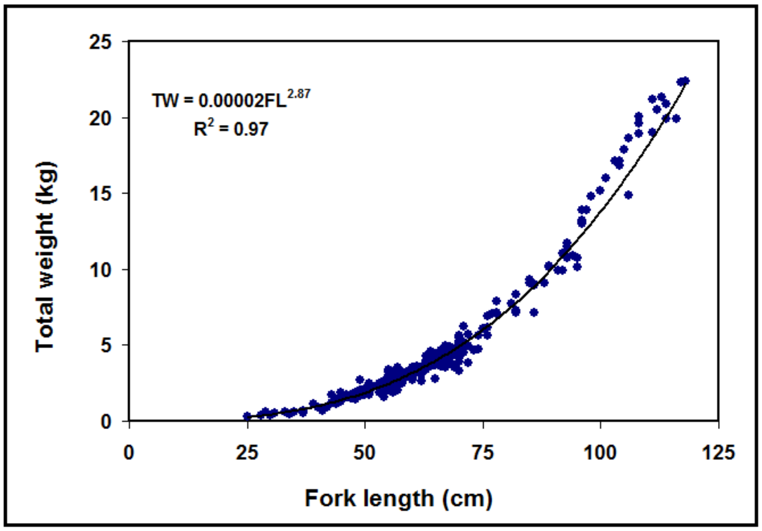

Fig.3. Relationship between total weight (TW) and fork length (FL) of longtail tuna in Northern of the Persian Gulf and Oman Sea (2015-2016)

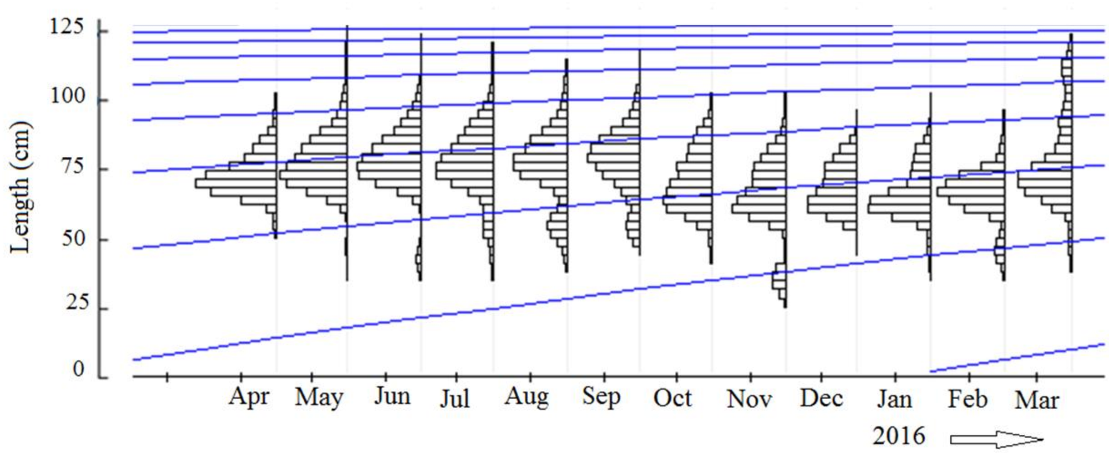

Fig.4. Monthly length frequency distribution output from FiSAT II with superimposed growth curve of *T. tonggol* in Northern of the Persian Gulf and Oman Sea (2015-2016)

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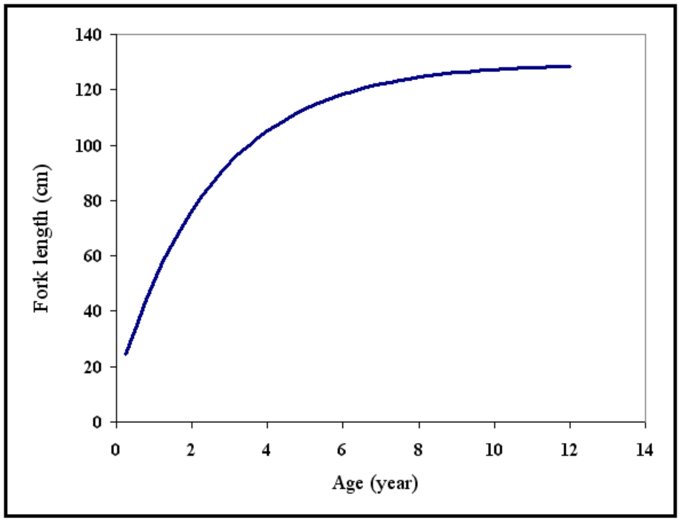

Fig.5. Length at age of *T. tonggol* based on Von Bertalanffy growth parameter from Northern of the Persian Gulf and Oman Sea (2015-2016)

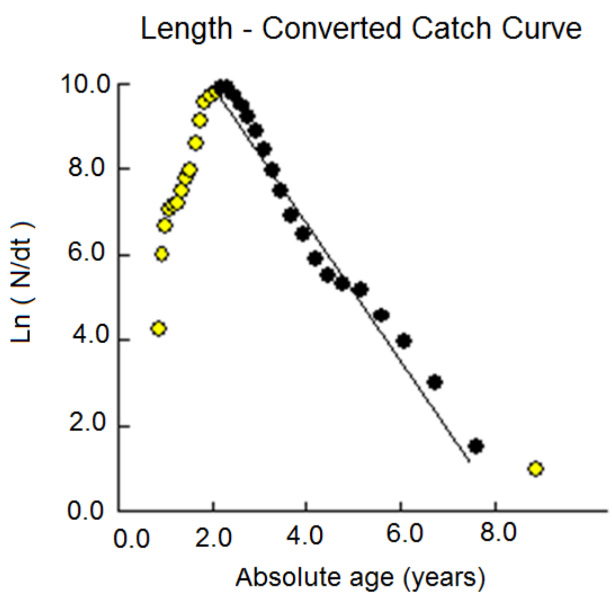

Fig.6. Length-converted catch curve for *T. tonggol* in Northern of the Persian Gulf and Oman Sea (2015-2016). Black dost are those used in calculating the parameters of the straight line, the slope of which is an estimate of Z. Yellow dots represent fish not fully selected by the gear used in the fishery and/or not used in mortality estimation

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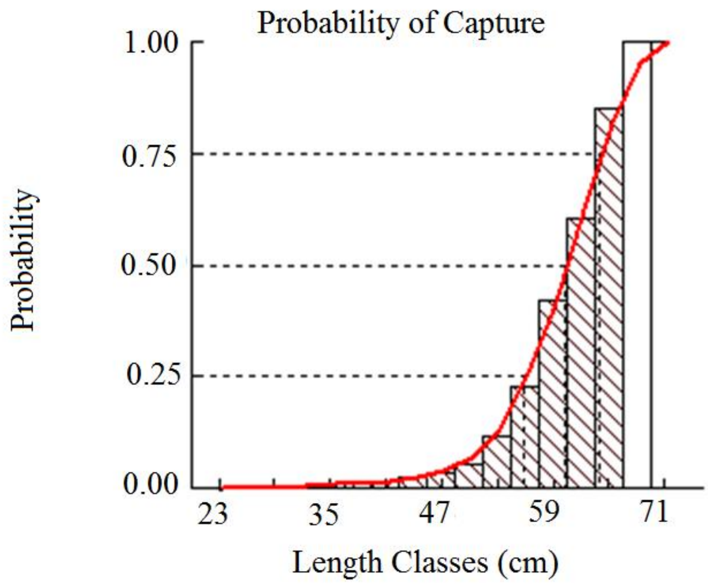

Fig.7. Probability of capture curve of longtail tuna in Northern of the Persian Gulf and Oman Sea (2015-2016) ($L_{50\%}$ = 60.2 cm fork length)

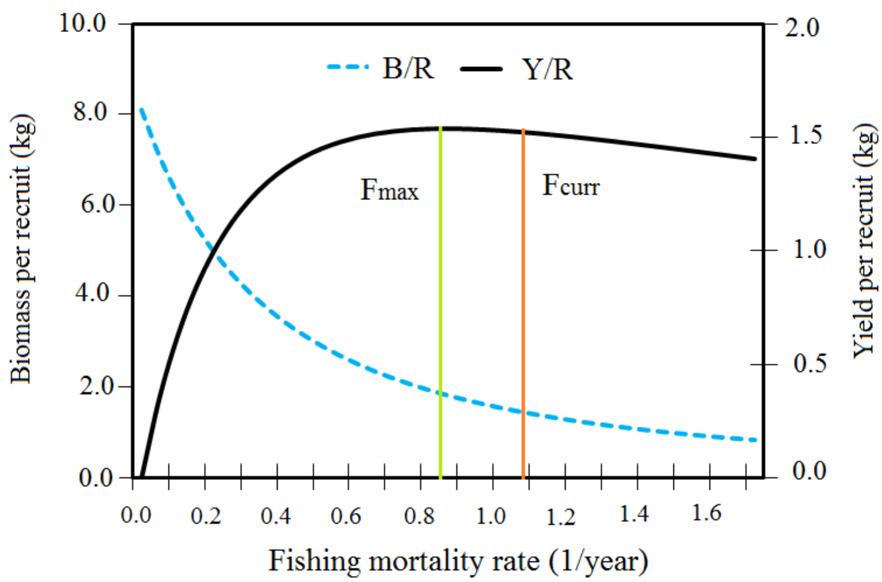

Fig.8. Yield per recruit and Biomass per recruit curves of longtail tuna in Northern of the Persian Gulf and Oman Sea (2015 - 2016) using the selection give option

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Table.1. Biological reference points for longtail tuna in Northern of the Persian Gulf and Oman Sea (2015-2016) (Lc = 60.2 cm, M = 0.49 $year^{-1}$)

Reference point	$F_{0.1}$	F_{max}	F_{opt}	F_{limit}
Value	0.47	0.85	0.25	0.33

Discussion

Fish stock assessment should be carried out for each stock separately, since an essential characteristic of a stock is that its population parameters remain constant throughout its area of distribution, therefore in the study we assumed that *T. tonggol* belongs to unit stock.

The size range of the individuals was between 25-124 cm fork lengths. Size frequency distribution can provide information on population dynamics in processes such as growth, mortality, recruitment, and population migration (Azpeitia *et al*., 2013). The size of longtail tuna taken by the Indian Ocean fisheries typically ranges between 15–120 cm depending on the type of gear used, season and location. The fisheries operating in the Andaman Sea (coastal purse seines and troll lines) tend to catch longtail tuna of small size (20–45cm) while the drifting gillnet fisheries operating in the Arabian Sea catch larger specimens (50–100 cm) (IOTC, 2015). Although the type of sampling gear may introduce a bias in the size structure of the fish, in this current study the use of different gill nets allows for representation of all exiting sizes of the longtail tuna.

Estimates of the condition factor and allometry coefficient can be related to ecological processes and life history. The length-weight relationship of *T. tonggol* is gave an isometric growth for this species in our study (a=0.00002, b= 2.87, R^2=0.97). Fish growth is generally isometric, and longtail tuna showed this growth pattern. High values of the allometry coefficient imply that the species gains weight fast growing in length. The value of the coefficient estimated for a species can vary between stocks and even between areas. In general, the coefficient b from length–weight relationship takes over the values in range 2-4 (Weatherly, 1972). James *et al*. (1993) estimated the values of **a** and **b** as 0.000083 and 2.71 respectively for longtail tuna in Indian coastal waters. In Australia the length-weight relationship of *T. tonggol* was $W=0.00005L^{2.82}$ (Griffith *et al*., 2010). Differences in **a** and **b** values may be due to the changes environnemental parameters, such as physiology of the fish, sex, development of gonads and conditions in respect of nutrition in the fish environment, as well as sampling date, region and methods (Pitcher, 2002).

Several methods are used to indicate growth estimates: analysis of tag and recapture data, analysis of the hard parts of the fish (otoliths, vertebrae, etc.), and analysis of cohort progressions in length-frequency distribution (modal progression) (Gaertner *et al*., 2004).

In tropical areas, the hard parts changes are less pronounced , therefore it is difficult to use a seasonal ring for age determination (Sparre and Venema, 1992) so, the analysis of length frequency data has been used for growth of fish by indicating cohorts or age groups (Bhattacharya, 1967).

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The growth parameters (K, L∞) of *T. tonggol* in this study were (0.39 year^{-1},129.6 cm) from the Persian Gulf and Oman Sea. Earlier authors have reported their estimation on growth parameters of longtail tuna based on otoliths and length frequency data (Table.2).

The growing constant, which indicates us the speed with which a fish approaches the asymptotic length (maximum theoretical) and it, has been also demonstrated that it is bound to the fish longevity (Beverton and Holt, 1959). Well, the bigger the value of this constant is, the smaller the longevity is. The differences in Von Bertalanffy growth parameters may be due to the various estimation models, differences in the maximum size of fish in different area, differences in genetic structure and/or density of food (Pauly, 1994). *T. tonggol* grow rapidly early in life, reaching a length of at least 50 cm after 1 year (Griffiths *et al*., 2010) and present study showed that longtail tuna grows very fast in the first 2 years.

Begg and sellin (1998) suggested that the fast growth strategy during the early stages most vulnerable to predation is typical of large prey species like Scombridae. The age at zero length in our study was -0.28. King (2005) suggested, negative t_0 indicates that juveniles grow more quickly than the predicted growth curve for adults.

Errors in the estimative of the growth fish parameters can be evaluated using the growth performance Index(φ) (Pauly and Munro, 1984) and species within the same family are expected to have similar φ values (Moreau, 1987). The growth performance index values ranges between 8.3-8.9 (Table 2) and φ value in the present study as compared to the earlier reported value is found comparable, maybe suggests a similar growth pattern across different stocks.

Table.2. Estimates of growth parameters for *T. tonggol* in the Indian and Pacific oceans by various analysis method

Area	**L∞(cm)**	**K(yr $^{-1}$)**	**t_0(yr)**	**φ**	**Method**	**Reference**
India	93	0.49	-0.24	8.3	Length-frequency	Silas *et al*., 1986
Japan	55	1.7	-0.089	8.5	Otoliths	Ioth *et al*., 1999
Thailand	108	0.55	-	8.7	Length-frequency	Yesaki, 1989
Iran	133.8	0.35	-	8.7	Length-frequency	Kaymaram *et al*., 2013
Oman	133.6	0.228	-	8.3	Length-frequency	Prabhakar and Dudley, 1989
Australia	135.4	0.233	-0.02	8.3	Otoliths	Griffiths *et al*., 2011
Papua New Guinea	122.9	0.41	-0.032	8.7	Length-frequency	Wilson, 1981a
Papua New Guinea	131.8	0.395	-0.035	8.8	Otoliths	Wilson, 1981b
Australia	110	0.32	-0.36	8.3	Length-frequency	fishbase
Thailand	58.2	1.44	-0.027	8.5	Length-frequency	Supongpan & Saikliang, 1987
India	123.5	0.51	-0.032	8.9	Length-frequency	Abdussamad *et al*., 2012
Iran	149.5	0.3	0.06	8.8	Length-frequency	Khorshidian & Carrara, 1993
India	99	0.48	-	8.4	Length-frequency	James *et al*., 1993
India	145	0.324	-	8.8	Length-frequency	Froese & Pauly , 2007
Iran	140	0.27	-	8.5	Length-frequency	Darvishi *et al*., 2003
Iran(Hormuzgan)	129.6	0.39	-0.28	8.7	Length-frequency	Present study

The mortality rates are important to calculating of optimal fishing effort in fisheries development. The total mortality of our study was 1.58 year^{-1}. This mortality rate of

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T. tonggol is smaller than the total mortality of this species reported by Abdussamad *et al.* (2012) (Z=3.72 $year^{-1}$) in West Indian coastal waters and greater than the estimate given by James *et al.* (1993) (Z=1.22 $year^{-1}$) in the Indian coastal waters. The variations in these values might have been caused by size specific selectivity by different fishery gears of longtail tuna or seasonal migrations. However even small fluctuation of growth parameters may influence on calculated mortality rates.

The perfect measurements of the natural mortality of the fishes are impossible and reliable estimate of M can only be obtained for an unexploited stock (Al-Hosni and Siddeek, 1999). Separating M and F from Z in a heavily exploited stock was a difficult task (Shojaei *et al.,* 2007) and to date the existing methods are based on empirical equations that have been tested for some groups of organisms, mainly fish (Pauly, 1980).

The natural mortality in this investigation was 0.49 $year^{-1}$. Prabhakar and Dudley (1989) and Kaymaram *et al.* (2013) were estimated natural mortality 0.429 and 0.44 $year^{-1}$ for *T. tonggol* in Omani and Iranian coastal waters respectively. Natural mortality is dependent upon mean temperature of water during the sampling data, disease and present predators in area. The fishing mortality and exploitation rate were 1.09 $year^{-1}$ and 0.69 respectively. Gulland (1970) was reported that in optimally exploited stock F(fishing mortality) should be equal M(natural mortality)and it is in case E=0.5, but Patterson (1992) observed that optimal E=0.5 tended to reduce pelagic fish stock abundance (i.e.*T. tonggol*) and suggested that E should be equal 0.4 for optimal exploitation.

One major reason why fisheries scientists study fish growth, and describe it by means of the von Bertalanffy growth function (VBGF), is to perform stock assessments using the yield per recruit (Y/R) model of Beverton and Holt (1957), or one of its variants (Pauly and Soriano, 1986). When little data on catch and fishing effort are available, yield per recruit models might be very profitable tools for assessment of fish population (Gabriel and Mace, 1999).

The yield per recruit curve showed that the maximum fishing mortality rate (Fmax=0.85 $year^{-1}$), which gives maximum yield per recruit, differs from the current fishing mortality rate (1.09 $year^{-1}$) estimated in this study. Theoretically, increasing length at first capture (Lc) motivate increase in yield. This will occur when the mesh size of designed gillnet allows immature fishes to escape and provide an opportunity for them to spawn at least once. Additionally, biomass per recruit showed decrease in current biomass to 17.2% of unexploited biomass at Fcurr. The critical range of spawning stock biomass is between 20-50% of unfished biomass (King, 1995), therefore *T. tonggol* have recruitment over fishing pattern in Northern of the Persian Gulf and Oman Sea coastal waters.

Biological reference points can provide guidance principles to fishery researchers to manage the stock. The current fishing mortality rate of 1.09 $year^{-1}$ considerably greater than ideal fishing mortality(F_{opt}=0.25$year^{-1}$) and limit fishing mortality (F_{limit}=0.33$year^{-1}$)biological reference points and indicating that population of *T. tonggol* is heavily overexploited in the Persian Gulf and Oman Sea. The $F_{0.1}$ computed 0.47 $year^{-1}$. In optimal yield, current fishing mortality do not exceed $F_{0.1}$ that is against our results in this

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study. Unfortunately, there are limited reports on population assessment of longtail tuna based on yield per recruit models in its global distribution. Using relative yield per recruit models, Abdussamad *et al*. (2012) indicated that longtail tuna are currently being fished at biologically sustainable levels, with considerable scope for increasing their yield in west coastal water of India.

In Australian coastal waters under all MLL (Minimum Legal Lengths) scenarios, the current fishing mortality rate did not exceed biological reference points however, there is potential for recruitment overfishing if the true age-at-maturity is higher than the estimate of 2 years old (Griffiths et al.,2010).

In conclusion, present study was the first population assessment using the yield-per-recruit model for longtail tuna in the Persian Gulf and Oman Sea and all results of investigation demonstrated that this species was not at the stable condition. The appropriate management of *T. tonggol* resource in this area needs to control fishing effort activities and gillnets mesh size. In the last decade (2006-2015) total catch of *T. tonggol* in Hormuzgan province (data sampling region) increased from 12,465 to 32,648 t (Iranian Fisheries Statistical Yearbook, 2006-2015) and this fishing pattern should be revised and it requires the participation of all fishermen and fishery managers and according to the last study of IOTC staff, the longtail tuna stock is considered to be ‘ overfished ’ (IOTC, 2015). As longtail tuna stock is to be considered as a transboundary fish stock, so its fishery management should be conducted in collaboration with countries bordering the Indian Ocean.

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