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Estimates of Length-Based Population Parameters of Yellowfin Tuna (*Thunnus albacares*) in the Oman Sea

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Abstract

This document analyses some population parameters of yellowfin tuna (*Thunnus albacares*) taken by drift gillnet operation from southern part of Iranian coast in the Oman Sea during 2007 to 2009. A total of 9,345 specimens of *T. albacares* were sampled in the size range of 37 cm to 172 cm fork length (FL). The mean length was estimated to be 86.12 cm. There was influence from seasonal variation on the length distribution of individuals, and it showed a tendency of gradual increase in the model length with the fishing season.

The temporal change in length distribution is more likely to be an indication of feeding migration of medium-sized yellowfin tuna from the western Indian Ocean into the Oman Sea during January to June. The statistical analysis of length-weight relationship was achieved by sex. The electronic package "ELEFAN I" was chosen for describing the species' von Bertalanffy growth equation; parameters were L_∞= 183.3 cm, K= 0.45 year^{-1}, and t_0= -0.184 year. Natural mortality (M) was 0.48 year^{-1}, fishing mortality (F) 1.56 year^{-1}, and total mortality (Z) 2.04 year^{-1}. The exploitation ratio (E) was as high as 0.76. For sustainable exploitation of *T.albacares,* a decrease in fishing effort of the gillnet fishery would be alternatively an effective measure to decline the fishing pressure on the stock, and to prevent the probably overfishing events.

Keywords: Length distribution, growth and mortality parameters.

Introduction

Yellowfin tuna, *Thunnus albacares*, as a tropical tuna, is a large, long-lived and high migratory pelagic fish which are distributed in temperate and tropical oceans around the world between 40ºN and 40ºS (Collette and Nauen, 1983). FAO reported that the yellowfin tuna landing amounts to 1,165,296 tons in 2011, making it the second largest tuna fishery worldwide after skipjack, *Katsuwonus pelamis,* with 25,230,011 tons (Anonymous, 2011a).

In Indian Ocean, fishing techniques engaged in yellowfin tuna harvest include purse seine, longline, gillnet, handline and pole-and-line fleets, with the majority of the catches comes from purse seine. Total annual catches averaged 372,200 tons over the period 2005 to 2009, with a peak at 503,700 tons in 2005. Catches in 2009 were 288,100 tons which is the lowest catch since 1991 (Anonymous, 2010).

Tuna account for 38% of the total marine fish landed in southern coastal waters of Iran in the Oman Sea, making a major contribution to the economy of the fishermen. Yellowfin tuna represents the second largest tuna catch encompassing 19% of the total fishery of this region which was estimated at 155,306 tons in 2011. The catch is predominantly made by the artisanal drift gillnets, with the minority (i.e., around 5%) being taken from industrial purse seine fishery. The artisanal fishery is affected by rough seas and strong currents produced from the southeast monsoon blowing from June to September so that the fishing activities remain limited during the violent situation of sea. Two kinds of boat are engaged for the artisanal fishery: fiberglass open boats and wooden dhaws so called launch. The larger dhows operate far away from the shore with an average catch of around 20 to 25 tons per trip.

Knowledge of fish population structure and status is essential for policy makers and stock managers to provide planning for resource management. Without it there are no bases upon which to understand fishery pattern changes and issues such as habitat destruction, predation and optimal harvesting rates. Of these, the population dynamic parameters including temporal distribution of length frequency, age, growth and mortality are necessary for any reliable stock assessments, and to ensure a sustainable exploitation of the fisheries

(Chen and Paloheimo, 1994).

There are still arguments about the estimation of population dynamic parameters, especially on growth performance, in Indian Ocean (Anonymous, 2010). These uncertainties can be explained by the restricted size range of yellowfin tuna available to the analysis (in particular the absence of small-sized fish), the lack of validation in the hypothesis of annual or semi-annual marks on the hard parts, the problems in the inherent to the length frequency method, and the existence or not of a phase of decreasing growth rate for fish during morphological and physiological adaptations (Lehodey and Leroy, 1999).

Several studies have been made extensively on population dynamic parameters of yellowfin tuna in Indian Ocean using a variety of techniques. They include modal analysis based on length frequencies (Anderson, 1988; Marsac, 1991; Somvanshi *et al.*, 2003; Ramalingam *et al.*, 2012), the deposition of growth bands on the hard structures such as otolith, scale and vertebrae (Nootmorn and Panjarata, 2001; Huang *et al.*, 1973; Romanov and Korotkpva, 1988) and the direct estimate from the analysis of releasing-recapture data of tagged fish (Eveson *et al.*, 2012; Cayré and Rancharrun, 1990), and the results are still open to debate. These different studies in various sectors of Indian Ocean are important to have a clear understanding on the stock structure. Numerous studies were also made on the age, growth and mortality parameters of yellowfin tuna in Atlantic Ocean (Lessa and Duarte-Neto, 2004; Manooch and Hinkley, 1991; Shuford *et al.*, 2006) and in Pacific Ocean (Lehodey and Leroy, 1999; Zhu *et al.*, 2011; Sue *et al.*, 2003; Suzuki, 1971).

In the present study, an investigation was made on important population dynamic features of yellowfin tuna using length-frequency data from Iranian artisanal fleets of drift gillnets in the Oman Sea. The main objective is to provide the length frequency distribution by season, and the growth and mortality parameters using the Electronic Length-Frequency Analysis "ELEFAN I" technique. The correlation between the length-weight is given by sex and combined case. The results given herein are expected to provide references for better knowledge of yellowfin tuna resource in the Oman Sea and to be fruitful in managing the developing fishery of the species in the area.

Materials and Methods

Yellowfin tuna random samples were collected monthly between September 2007 and October 2009 at major landing sites in the Oman Sea from east to west (Beris, Ramin, Chahbahar, Pozm, Jask) using drift gillnet (Figure 1).

A total of 9,345 specimens were sampled for their length and weight. Fork length of all samples was recorded to the nearest 1 cm and the whole wet weight (TW) was taken with a balance and recorded to the nearest 100 grams. Data were pooled monthly and subsequently grouped into length classes at 3 cm intervals; length frequency data were then analyzed using "ELEFAN I" routine of the FISAT II program package (Gayanilo and Pauly, 1997). The length interval of 3 cm was chosen because the length distribution is clearly distinguishable by the size group. Using size group more than 3 cm is expected to have some erroneous parameters estimated from the relevant equations.

Length-Weight Relationship (LWR) has a great importance in fishery biology, especially its application in the stocks assessment of aquatic species (Enin, 1994; Stergiou and Moutopoulos, 2001). The relationship between fork length and total body

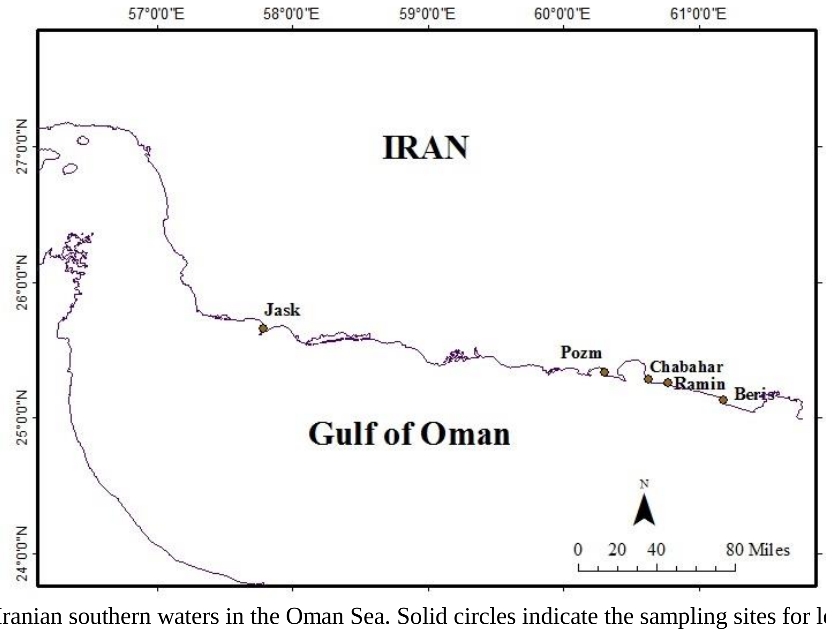

Figure 1. Map of Iranian southern waters in the Oman Sea. Solid circles indicate the sampling sites for length-frequency data collection.

weight was determined by the expression (Pauly, 1983):

$$w = aL^{b}$$

Where W is the total weight (kg) derived from the equation, L is the fork length (cm), *a* the intercept of the least square regression curve (initial growth coefficient), and b the slope of the regression (growth coefficient, i.e., relative growth rate of fish). The parameters 'a' (intercept) and 'b' (slope) are easily estimated by linearization of the power curve describing the best fit; both variables were transformed using natural logarithms based on as (Lagler, 1968):

$$LnW = Lna + bLnL$$

The value of "b" lies between 2.5 and 3.5, and often close to 3 (Pauly, 1984). To test whether a value of b is significantly different from 3, isometric growth pattern, we used the below t-test equation (Pauly, 1984) as:

$$\hat{t} = \frac{s.d._{(x)}}{s.d._{(y)}} . \frac{|b-3|}{\sqrt{1-r^2}} . \sqrt{n-2}$$

Where $s.d._{(x)}$ is the standard deviation of the LnL values, and $s.d._{(y)}$ the standard deviation of the LnW values, n being sample size used in the computation and r^2 the determination coefficient. ANCOVA was used to test the potential effect of sex on length-weight relationship. If sex was not significant the data were pooled and a single length-weight relationship was calculated to describe a general relationship (Zar, 1999). The strength of the LWR was evaluated by means of the correlation coefficient (r).

Maximum length of fish (L_{max}) was predicted using Maximum Length Estimation routine from the Support menu of "ELEFAN I". The best value of growth parameter (K) for the given value of L_{max} was identified by Shepherd's method when we used scan of K-values option from Assess menu. A classical von Bertalanffy growth function (VBGF) (Sparre and Venema, 1998) was fitted to the data using the following formula:

$$L_t = L_\infty (1 - \exp(-K(t - t_0)))$$

In this equation t_0 represents the theoretical age at length zero, L_∞ is the asymptotic length, L_t is the length at age t.

L_∞ was taken from Powell-wetherall plot which used length frequencies data with equation given thus:

$L_\infty = - a/b$

Where b is the slope and a the intercept of the regression.

Longevity or maximal age (t_{max}) of yellowfin tuna was estimated using the equation proposed by Pauly (1984):

$$t_{max} = t_0 + 2.996 / k$$

Estimate of the t_0 parameter was determined by empirical equation proposed by (Pauly, 1979).

$$Log_{10}(-t_0) = -0.392 - 0.275Log_{10}L_\infty - 1.038K$$

Natural mortality (M) was estimated using indirect method based on relationships with life history parameters. We used Pauly's empirical equation (1980) based on L_∞, K and the mean annual sea surface temperature (26.5ºC) measured directly from the sea trials conducted regularly in our area. The total fishing mortality (Z) of yellowfin tuna was estimated using Z/K ratio which was derived from Powell-wetherall plot (Sparre and Venema, 1998) with equation such that:

$Z /K = - (1+b) /b$

Total mortality (Z) was then estimated from Z/K ratio. The fishing mortality rate (F) was derived from the difference between (Z) and (M). The rate of exploitation (E) was calculated by the quotient between fishing and total mortality (Pauly, 1984).

Results

The annual frequency distribution from monthly samples showed that the exploited sizes ranged from 37 to 172 cm FL, while the mean length was estimated at 86.12 cm (Table 1). The overall histograms from Figure 2 present a higher frequency (80% of the total fish sampled) at length range from 54 to 102 cm FL, while fork length at 103 cm the frequency dropped down dramatically and continued its rather regular decreasing trend since then. Individuals more than 100 cm FL consisted of about 18% of the population.

The seasonality of yellowfin tuna sizes for the gillnet fishery is illustrated in Figure 3 where sizes have been grouped by quarter. From this figure, the seasonal pattern is quite clear at modal length for each quarter. The modal size of yellowfin tuna is gradually increasing from 61 cm FL at the fishing season in October-December (the first term is considered as the start of fishing season) to 93 cm FL in the fourth quarter of the season in July-September during monsoon period.

These features are better illustrated in Figure 4, where sizes have been gathered in four groups. The proportion of the small group (37 to 61 cm) decreases from 40% at the beginning of the fishing season (October-December) to 13% at July-September. By contrast, the portion of larger fish with size group of

Table 1. Statistical results of biometric parameters of yellowfin tuna in the Oman Sea (2007-09)

Biometric parameter	Number	Mean	Minimum	Maximum	S.d[1]	S.e[2]
Fork length (cm)	9345	86.12	37	172	21	0.22
Total weight(kg)	531	11.4	3.2	44.2	6.31	0.27

[1] S.d= standard deviation
[2] S.e= Standard error

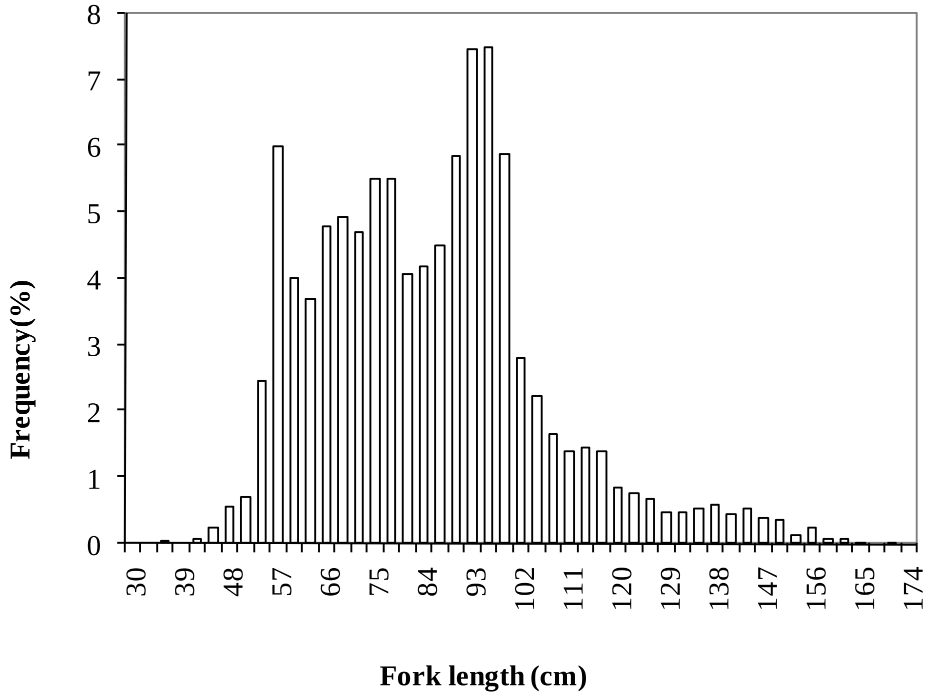

Figure 2. Length frequency distribution of yellowfin tuna taken by drift gillnets in the Oman Sea (2007-09).

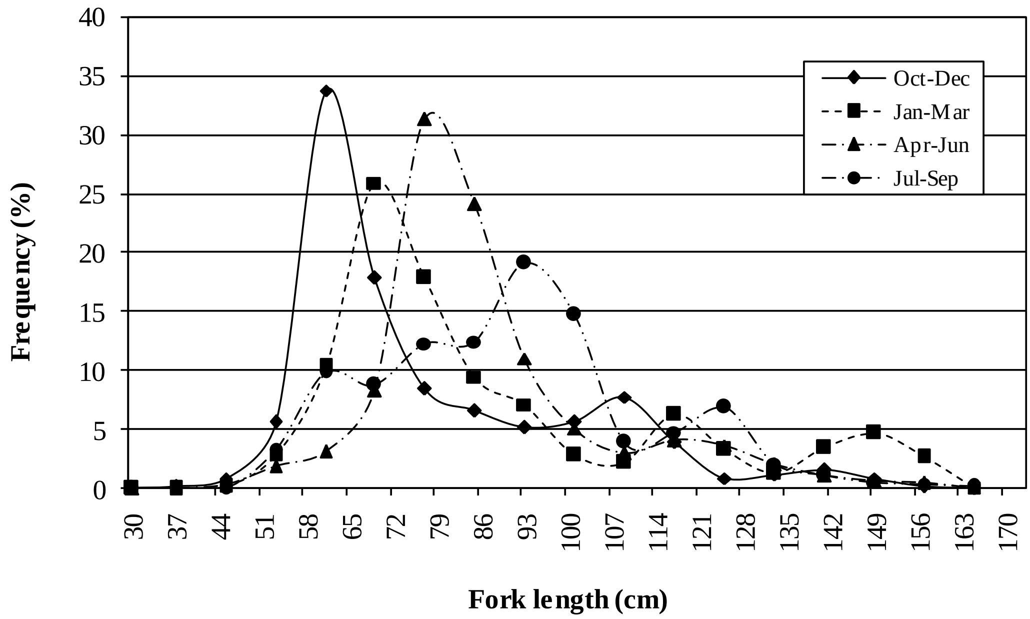

Figure 3. Yellowfin tuna size distribution by quarter in percentage of each size class taken from the drift gillnets in the Oman Sea (2007-09).

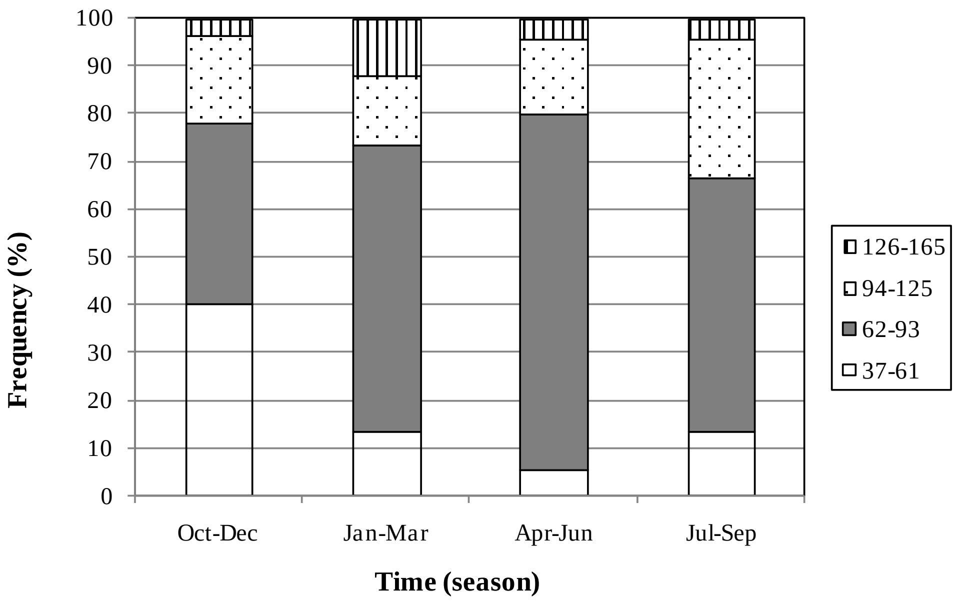

Figure 4. Yellowfin tuna size distribution by quarter in four different size groups taken from the drifting gillnets in the Oman Sea (2007-09).

62-93 cm FL increased from 38% at the beginning of fishing season to 53% at the fourth quarter of the season.

Using 531 samples obtained from the study area, the equation of length-weight relationship was determined by power equation for male and female (Figure 5). Based on the results, the intercept, a, was estimated to be 0.000035 and 0.000036 for male and female, respectively. The intercept, a, value for combined sexes was estimated at 0.000034. Analysis of t-test identified a negative allometric growth in all cases and it did not follow the cube law as shown by slops b = 2.831 for male, b = 2.829 for female, and b= 2.838 for combined sexes ($P<0.05$). Generally, the regression equations revealed high correlation in both sexes as the correlation coefficient (r) values for each case are very close to 1 (Table 2). ANCOVA was performed to test the significant difference in length-weight relationship between sexes and the relationship was not found to be significant.

The range of extreme length, L_{max}, was arrived as 174.95-206.94 cm FL at 95% confidence level and it was predicted to be 190.94 cm (Figure 6). Accordingly, K value was 0.45 $year^{-1}$ (Figure 7). L_∞ and Z/K were 183.3 cm and 4.6, respectively, by Powell-Wetherall plot based on the following linear regression equation (Figure 8):

$$Y = 33 + (-0.18) \times X$$

The regression line identified the first length at fully exploitation (L') of 103 cm FL which coincides with one length to the right of the highest mode in the length-frequency data (102 cm in Figure 2)

The theoretical age at length zero (t_o) of the von Bertalanffy model was estimated at -0.184 year. The longevity, t_{max}, of yellowfin tuna was 6.5 years, with the growth performance index (φ) of 4.21. The Von Bertalanffy growth equation was driven as:

$$L_t = 183.2(1 - e^{-0.45(t+0.184)})$$

Taking t_0= -0.184 the length of the yellowfin tuna was calculated as 75.67 cm, 114.64 cm, 139.48 cm,155.32 cm,165.43cm, 171.87 cm,175.97 cm at 1 to 7 years respectively.

Natural mortality (M) was calculated at 0.48 $year^{-1}$ and fishing mortality (F) at 1.56 $year^{-1}$. Taking Z= 2.04 into account, an exploitation level (E) of 0.76 $year^{-1}$ was obtained for *T. albacares* fishery in the Oman Sea, which seems to be upper than the expected optimum level of exploitation (E = 0.50).

Discussion

The present study indicated that the range of yellowfin tuna exploited by drift gillnet in the Oman Sea to be within 37 to 172 cm FL. The size of yellowfin tuna exploited in the Indian Ocean ranges from 30-180 cm FL depending on the different fishing grounds (Anonymous, 2011b). Hallier (2003) reported that the fork length of yellowfin tuna taken from gillnet fishery are within the 40-165 cm range in the Oman Sea, for which the majority specimens fall between 60 and 105 cm FL, similar to those obtained from the present paper (54 to 102 cm, see Figure 2). The size frequency of yellowfin tuna from tuna longline survey data was recorded to be ranged from 48-169 cm FL in the Indian EEZ around Andaman and Nicobar Islands (Ramalingam *et al.*, 2012).

Judging from the length distribution by season, a reduced proportion of small size group of yellowfin tuna (37 to 61 cm) from October-December to January-March along with an increase in size range of

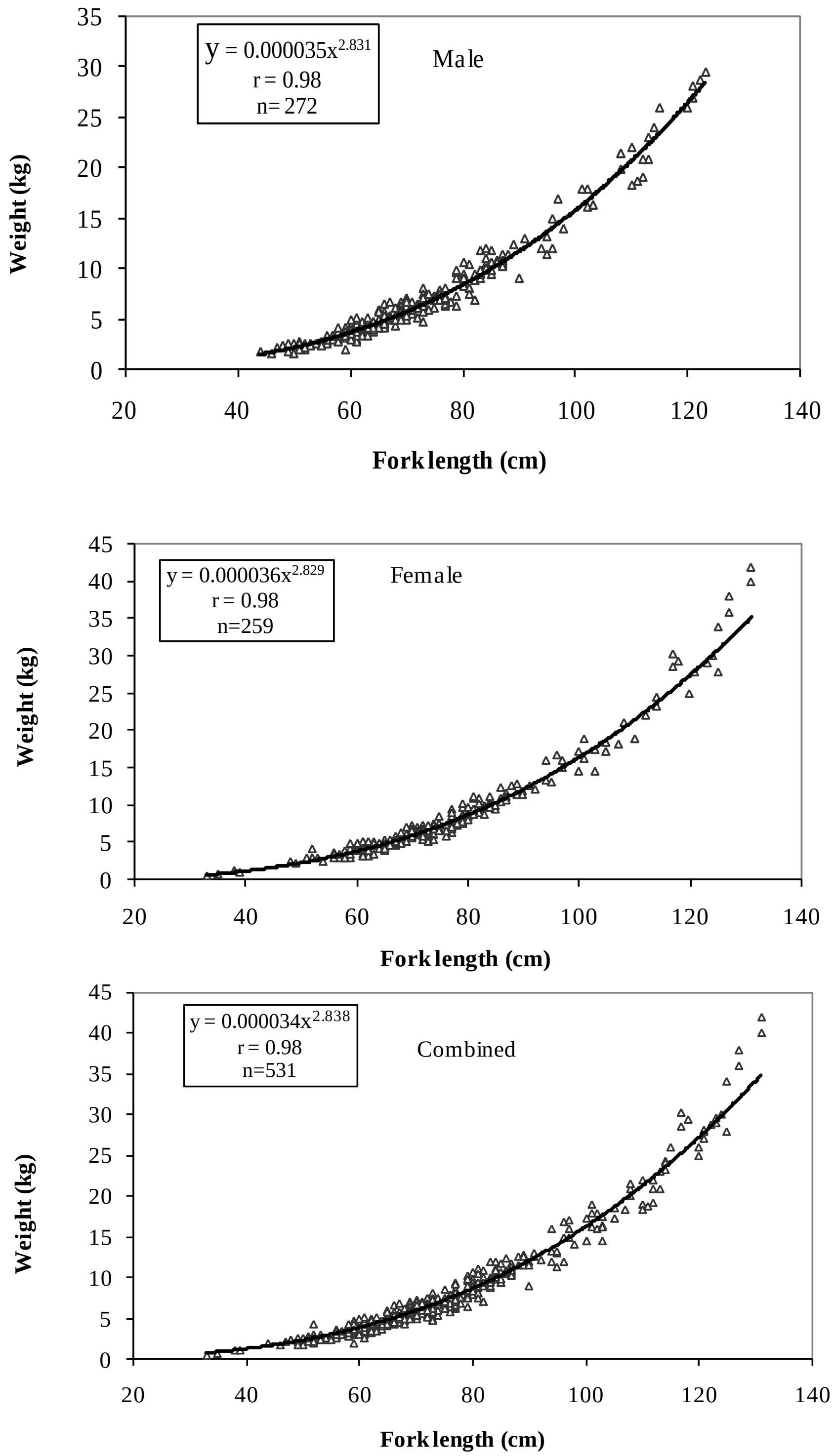

Figure 5. Length-weight relationship of yellowfin tuna by sex and combined sexes in the Oman Sea (2007-09). n: sample size.

Table 2. Least square regression, slop (b), intercept (a), correlation coefficient (r) of the length-weight relationship in yellowfin tuna

Sex	Regression Equation	r	b	a
Male	$W=0.000035L^{2.831}$	0.98	2.831	0.000035
Female	$W=0.000036L^{2.829}$	0.98	2.829	0.000036
Combined Sex	$W=0.000034L^{2.838}$	0.98	2.838	0.000034

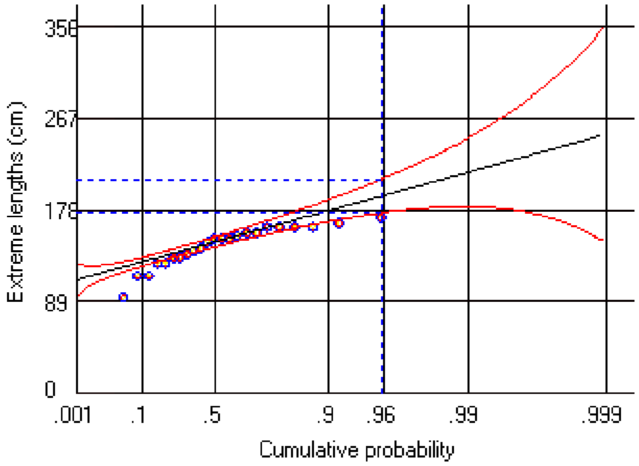

Figure 6. Facsimile representation of the resulting analysis of extreme values of yellowfin tuna in the Oman Sea (2007-09).

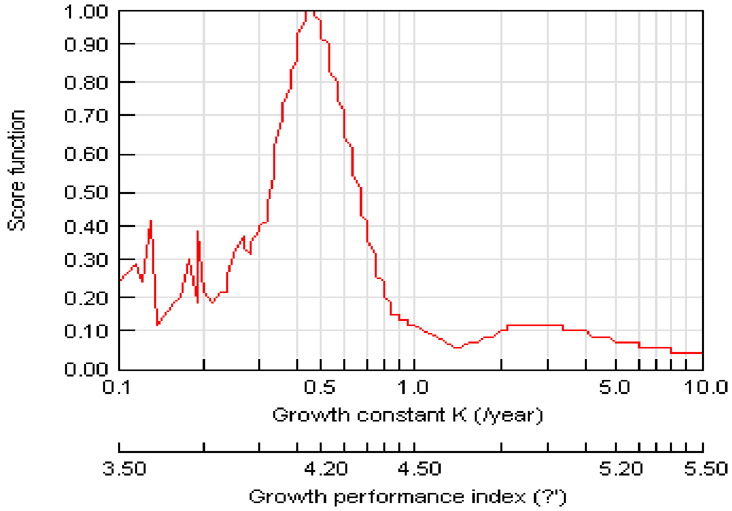

Figure 7. Shepherd's method with maximum score (S_{max}) appropriate to the best value of growth coefficient of yellowfin tuna in the Oman Sea (2007-09).

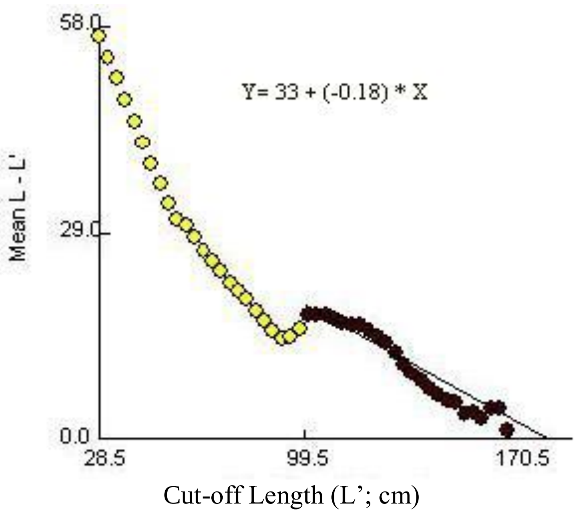

Figure 8. Powell-wetherall plot for yellowfin tuna in the Oman Sea (2007-09). The equation shows the relationship for the regression line.

62-93 cm may show that the smallest fish are just passing through the Oman Sea in January and are regularly replaced by the newcomer slightly big ones. The latter size range reaches it's the highest frequency up to 75% of the total catch in April-June period.

These data makes it possible to draw conclusion that the medium-sized yellowfin tuna moves from the western Indian Ocean into the Oman Sea for feeding during January to June. This period coincides with the feeding attitude of yellowfin tuna schools on sardines and anchovies at the sea surface from January to July when the small pelagic fish schools are frequently abundant in the Oman Sea and chased by the tunas (unpublished data). It is a more probable conclusion that the concentration of the small pelagic fish during the period would be as a consequence of upwelling caused by the southwest monsoon season. The productive value of upwelling is found to be reflected in the intensity of the primary and subsequently the secondary production (Rao *et al.*, 1992).

The presence of large number of 94 to 125 cm fish during July-September (29%), compared to other quarters, may suggest that many bigger fish are still moving into the area for the period. The fish probably leave the area in October-December where their quantities decrease to 18% of the total individuals.

During post-monsoon period from October to December, that is after upwelling, the movement of intermediate-sized yellowfin tuna away from the Oman Sea is thought to be owing to the low availability of the small pelagic fish to the tuna schools (unpublished data).

Regarding the stock structure, there would be little possibility of existing two different stocks of yellowfin tuna in the Indian Ocean. The stock assessment done regularly by the Indian Ocean Tuna Commission (IOTC) (Anonymous, 2010) is based on the hypothesis of a single stock of yellowfin tuna for the all Indian Ocean.

Somvanshi (2002) expressed that the length-weight relationship of yellowfin tuna stock in different areas and in entire Exclusive Economic Zone has no significant difference, and the exponential value "b" is 2.8 for all the sectors of Indian Ocean. These values were different for male and female (2.8653 and 2.7565 respectively) in the Andaman Sea. In the Eastern Indian Ocean, along Thailand coast, this value was estimated to be 2.793 and 2.723 for male and female respectively (Tantivala, 2000). The study by Ramalingam *et al.* (2012) showed an isometric growth for yellowfin tuna when the "b" values for male and female were 3.12 and 2.96, respectively, with significant difference in Nicobar and Andaman Sea. Although the present study revealed a negative allometric growth for yellowfin tuna, the "b" values (2.831 and 2.829 for male and female respectively) are close to the above findings.

The growth pattern of yellowfin tuna seems to be complex at different places of Indian Ocean. Yearly, consultations are made on the growth rate in the IOTC Working Party on Tropical Tuna for compliance purposes. Various studies in different sectors of Indian Ocean indicated that the L_∞ was varied from 170-197.42 cm, while the range for K was 0.20 and 0.66 (Table 3), suggesting the results by the present study (k and L_∞ perform the values of 183.3 cm and 0.45 $year^{-1}$ respectively) were consistent with the ranges. According to the table, a faster growth rate of yellowfin tuna was suggested by Anonymous (1987), Chantawong (1998), and Maldeniya and Joseph (1986) in comparison with our findings.

Moreover, the growth parameters presented here are also comparable with those of Kaymaram *et al.* (2000) who found K= 0.42 $year^{-1}$, L_∞= 189 cm and t_0= -0.23 year for the yellowfin tuna samples taken from the same area in Oman Sea.

Moreover, our findings indicated that the growth increment from one year to two years was 38.97 cm (from 75.67 to 114.64 cm) or 3.25 cm per month of yellowfin tuna. As suggested by Anderson (1988) the growth rate of 2.9 + 4 cm per month would be plausible. The growth increment was 24.85 cm with a rate of 2.07 cm per month when the fish grow up from age 2 to age 3, suggesting a slow growth rate for older individuals. The average growth rate was 1. 39 cm per month from age 1 to age 7.

Figure 9 compares the growth curve of yellowfin tuna between the present study and that of Somvanshi *et al.* (2003) and Ramalingam *et al.* (2012) from the Arabian Sea and Andaman & Nicobar waters. For the first three years, yellowfin tuna grows at a faster rate

Table 3. Growth parameters calculated for yellowfin tuna in different regions of Indian Ocean

Region/Sector	L_∞ (cm)	K ($year^{-1}$)	t_o	Longevity (yrs)	Source
Oman Sea	183.2	0.45	-0.184	6.5	Present study
Oman Sea	189	0.42	-0.23	-	Kaymaram *et al.* (2000)
Andaman & Nicobar Seas	173.3	0.39	-0.0999	7.69	Ramalingam *et al.* (2012)
Arabian Sea & A&N Seas	193.0	0.2	--	15	Somvanshi *et al.* (2003)
East coast of India	197.42	0.3	-0.1157	10.1	Prathibha *et al.* (2012)
Eastern Indian Ocean	194.0	0.66	0.27	11.1	Chantawong, (1998)
Sumatra	170.0	0.5	--	6	Anonymous (1987)
West coast of India	175.0	0.29	10.3	--	John and Reddy (1989)
Eastern Indian Ocean	185.68	0.34	-0.003	--	Tantivala (2000)
West & south of Srilanka	178.0	0.47	-0.208	6.38	Maldeniya and Joseph (1986)

in Oman Sea than in those areas mentioned.

The estimates of natural mortality vary widely, ranging from 0.4 year^{-1} for Prathibha *et al.* (2012) to 0.74 year^{-1} for John and Reddy (1989), as indicated in Table 4. These estimates are mainly based on indirect method (e.g. Pauly, 1980) and will therefore be sensitive to the growth parameters, K and L_∞. M is one of the most influential quantities in determining the sustainable exploitation level and the management reference points. The optimal exploitation rates are particularly sensitive to M, which is highly uncertain (Fonteneau and Pallares, 2005). In the present study, M was assumed to be constant over age, time, and gender, which the resultant value may be an unreliable estimate of the parameter (Vetter, 1988).

The fishing mortality of 1.56 year^{-1} revealed that the fishing pressure has increased in this area in the recent years. Gulland (1971) suggested that in a stock with optimum exploitation, fishing mortality should be about equal to natural mortality. In addition, results from the exploitation level of E=0.76 again implies that overfishing occurred in the Oman Sea.

Yellowfin tuna fishery in Iran was expended over the last decade (from 68,085 ton in 2001 to 155,306 ton in 2011) by the artisanal drift gillnet method. To optimally harvest the available stock of yellowfin tuna and to prevent the probably potential overfishing, one practical management strategy can be to decline the fishing effort of the gillnet fishery. Alternatively, restriction in the length of gillnet at each set would be an effective option to reach such a purpose. Presently, the net length at each deployment is as long as 8250 m for large dhow. This single piece of net is composed of 110 panels linked together, each measuring 75 m long (Hosseini *et al.*, 2006).

Yearly, meetings are held between the executive and research groups in Iran for reviewing the exploitation level of the tuna stock based on such population parameters presented here. Survey on differences in natural mortality by age, time and gender needs to be undertaken in future to validate the results obtained by the length frequency studies.

Acknowledgements

The data of this work were collected as part of a

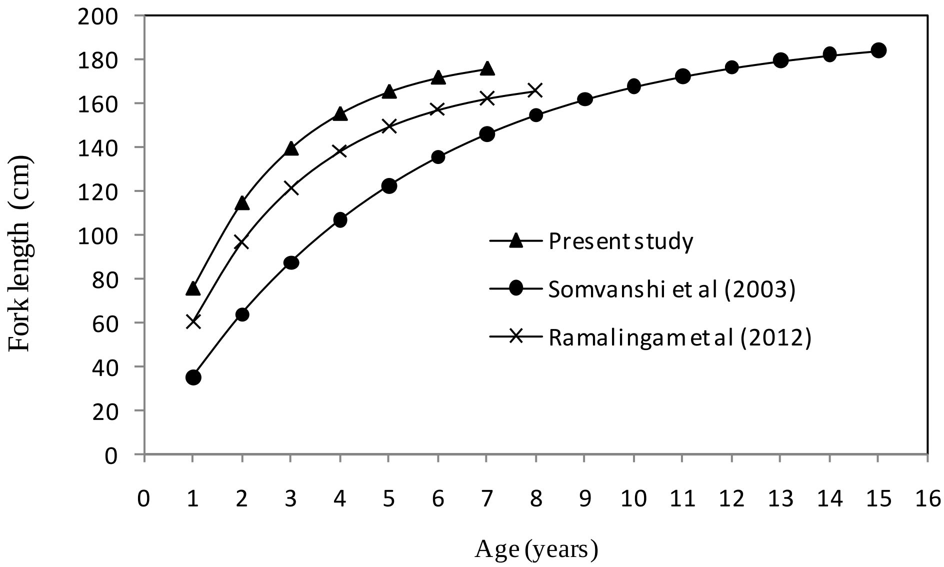

Figure 9. The comparative fork length at age of yellowfin tuna in the Oman Sea, Arabian Sea and Andaman & Nicobar waters (for detailed explanation, see text).

Table 4. Natural mortality (M) calculated for yellowfin tuna in different regions of Indian Ocean

Region/Sector	M (year^{-1})	Source
Oman Sea	0.48	Present study
Oman Sea	0.6	Kaymaram *et al.* (2000)
Andaman and Nicobar Seas	0.51	Ramalingam *et al.* (2012)
A &N Seas	0.60	John, (1995)
Lakshadweep Sea	0.49	Silas *et al. (*1985)
East coast of India	0.4	Prathibha *et al.* (2012)
West coast of India	0.74	John and Reddy, (1989)
Lakshadweep Sea	0.52	Pillai *et al.* (1993)
Indian Ocean	0.61 to 0.70	Yesaki, (1991)
Indian Ocean	0.54	Pillai *et al.* (1992)

larger project entitled" An investigation of fluctuation of large pelagic fish resources in Persian Gulf and Oman Sea " which was funded by Iranian Fisheries Research Organization (IFRO) along with the cooperation of Offshore Fisheries Research Center and Persian Gulf and Oman Sea Ecological Institute. We would like to thank the all technicians involved in the data collection.

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