Length-frequency, Yield and Biomass Per Recruit Analysis for Yellowfin Tuna, *Thunnus albacares* (Bonnaterre 1788) in the Arabian Sea off Oman

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Abstract

The present study was carried out to evaluate the stock of *Thunnus albacares* (Bonnaterre 1788) in the Arabian Sea off Oman. A random sample of 3,690 fish representing a wide range of total lengths (44-156 cm) and weights (3-64 kg) were collected from Al-Sharqya area, Oman from January to December 2007. Length-frequency analysis and yield and biomass per recruit models were used.Values of the von Bertalanffy growth parameters fit to size-at-age data were: asymptotic length ($L\infty$)=188.2 cm, curvature parameter (K)= 0. 33 year^{-1}, and hypothetic age at zero length (t_0) = −0.66 year. Using the length-converted catch curve, total mortality (Z) was estimated as 1.72 year^{-1}. Natural mortality coefficient M was 0.53 year^{-1}and fishing mortality coefficient F was 1.19 year^{-1}. The mean length at first capture (L_c) estimated from the analysis of probability of capture of each length class was 69.67 cm. The yield per recruit (Y/R) was 8,983 g per recruit(g/r), which is less than the maximum value (9,683 g/r) that could be obtained at a fishing mortality of 0.6 year^{-1}. The biomass per recruit (B/R) represented about 10 % of the virgin biomass, indicating a state of overexploitation. To increase the Y/R and B/R of *T. albacares* the results suggest increasing the length at first capture through increasing the mesh size of artisanal gillnets.

Introduction

The tuna fishery contributes significantly to the total fish landings in Oman and is considered one of the most important resources for artisanal fisheries. They are traditionally caught by Oman's fishermen in the Arabian Sea, Oman Sea and the Arabian Gulf, using drifting gillnets. During 2001-2006, tuna accounted for 20-25% of the total fish landings in Oman (Ministry of Fisheries Wealth (MAW), 1988–2006). Over 87% of the total tuna landings were harvested by the artisanal fleet during the same period.

Yellowfin tuna, *T. albacares* (Bonnaterre 1788) is the major component of the tuna fishery,and is the dominant tuna species in the large pelagic fisheries of Oman. It is the most economically important species in Omani waters, constituting over 55% of total tuna catch in Oman during 1988-2006 (MAW 1988-2006).

The main spawning ground of yellowfin tuna is the equatorial zone of the Indian Ocean (Somvanshi 2002). The juveniles migrate towards the coastal waters off the Arabian Sea, Gulf of Oman and Gulf Countries (Govindraj et al. 2000). When they reach the pre-adult age (60-80 cm at

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age 1.5-2 years), it is presumed that the majority migrate west towards the Arabian Gulf coasts (Govindraj et al. 2000). Consequently, most of these fish return to the fishing grounds in the Indian Ocean for spawning, when they reach about 110 cm in length (Govindraj et al. 2000). However, it is not known whether small-sized yellowfin tuna in Omani waters are allowed to reach the size of sexual maturity, which was reported to be 100 cm length or more (Maldeniya and Joseph 1988; Hassani and Stequert 1990; Timochina and Romanov. 1991**).** The dynamics of tuna stocks in Omani waters are also not fully investigated. There is currently a growing interest by the Omani government to study tuna fisheries in order to manage these important resources on a sustainable basis. Therefore, it is important to collect the necessary information to perform tuna stock assessment. Thus, the present study was carried out to investigate the population dynamics of *T. albacares* in Al-Sharqiya area, which is the most important tuna fishing area in Oman. The main objectives of the study were to estimate the growth parameters, mortality rates, and relative yield per recruit and biomass per recruit.

Materials and Methods

The data of yellowfin tuna (*T. albacares*) used in the present study were collected monthly from the commercial catch of surface gillnet from Al-Sharqiya landing sites, Sultanate of Oman, during January-December 2007. A total number of 3,960 fish representing a wide range of total lengths (44-156 cm) and total weights (3-64 kg) were sampled. The monthly length-frequency data were analysed using the FiSAT package (Gayanilo et al. 1997) and LFDA5 software (Kirkwood et al. 2001).

Growth estimates

The values of growth parameters, asymptotic length (L_∞), curvature parameter (K) and hypothetic length at zero length t_o were estimated using LFDA5 software (Kirkwood et al. 2001). Using these values the lengths at ages and growth increments were calculated according to Ford (1933) and Walford (1946).

Mortality estimates

The initial estimate of L_∞ was used to estimate the instantaneous total mortality coefficient Z. The value of (Z) was estimated by applying the length converted catch curve developed by Pauly (1983b):

$$Ln\frac{C(t,t+\Delta t)}{\Delta t} = c - Z(t + \Delta t/2)$$

Where: C is the catch and t is the age

Natural mortality (M) was estimated by using the growth parameters and the mean environmental temperature using Pauly and David's formula (Pauly 1980) for tropical species.

$\text{Log}_{10} M = 0.0066 - 0.279 \text{ Log}_{10} L_\infty + 0.6543 \text{ Log}_{10} K + 0.4634 \text{ Log}_{10} T$

Where, L_∞ and k are growth parameters and T is the mean annual water temperature

The annual instantaneous fishing mortality coefficient (F) was calculated by subtracting the natural mortality coefficient (M) from the total mortality coefficient (Z) derived from age based catch curves (F = Z−M), while the exploitation rate E was estimated as F/Z.

Yield per recruit and biomass per recruit

The yield per recruit (Y/R) and biomass per recruit (B/R) were determined as a function of the exploitation rate. The estimated yield per recruit is based on the Beverton and Holt (1966) model, as modified by Pauly (1983a).

$$Y/R = F/K * A * W_\infty (1/Z - 3U/Z+1 + 3U^2/Z+2 - U^3/Z+3)$$

Where: $A = (L_\infty - Lc / L_\infty - L_r)^{M/K}$

$U = 1 - (L_c / L_\infty)$

W_∞ = the Asymptotic weight

L_c = length at first capture,

L_r = length at first recruitment, L_∞ = Asymptotic length

K = von Bertalanffy growth coefficient

Z = Total mortality coefficient = (M+F) and

M = Natural mortality coefficient

F = Fishing mortality

The biomass per recruit (B/R) was estimated from the following equation:

$(B/R) = (Y/R) / F = K * A * W_\infty (1/(M+F) - 3U/(M+F+1) + 3U^2/(M+F+2) - U^3/(M+F+3))$

The virgin biomass per recruit is the biomass per rcruit when fishing mortality (F) equals zero

L_c = length at first capture was calculated using the following equation:

L_c= L- K (L$_\infty$ - L) /Z   (Beverton and Holt 1956)

Results

Growth

The length frequency distribution of yellowfin is given in Fig. 1. Fish length ranged from 44 - 156 cm with mean length of 82 cm. Fish less than 100 cm constituted more than 60% of the landed catch.
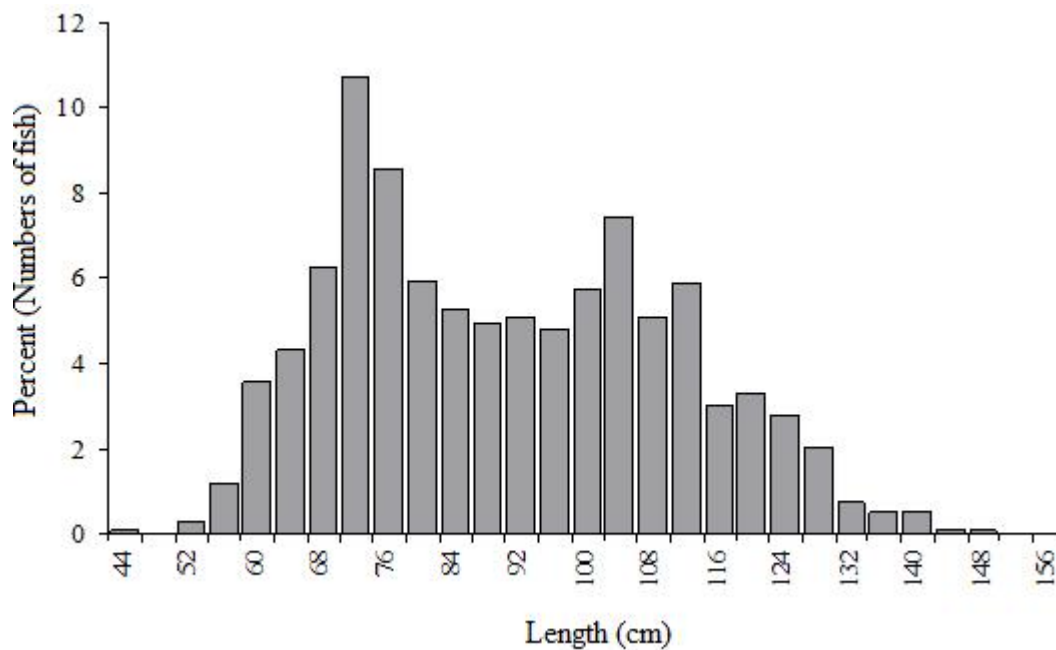

Fig. 1. Length frequency distribution of yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.

Length frequency analysis indicated that the landed catch of yellowfin tuna included five age groups with estimated lengths of 69.67, 110.5, 132.5, 148.28 and 159.58 cm, respectively as estimated according to Ford (1933) and Walford (1946). Figure 2 shows the growth curve (estimated lengths at ages) and growth increment curve.
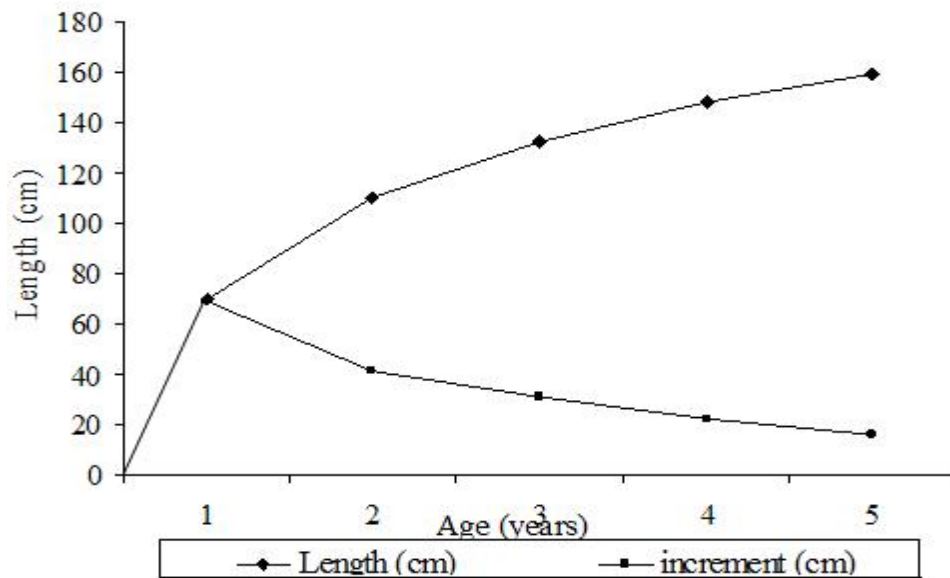
Fig. 2. The estimated length (cm) and increment at age (year) of yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.

The estimated values of growth parameters (L_∞, W_∞, K an t_o as obtained from the von Bertalanffy equation were L_∞ = 188.2 cm, W_∞ = 127.94 kg, K = 0.33 year^{-1} and t_o = -0.66 year, respectively.

Length-weight relationship

The length-weight relationship (Fig. 3) for yellowfin tuna was computed and found to be almost isometric, and represented by the following equation:

$$W = 0.0000196 \times L^{2.996}$$

Yield per recruit and biomass per recruit

At current values of length at first capture (69.67 cm), natural mortality (0.53 year^{-1}) and fishing mortality (1.19 year^{-1}), the yield per recruit (Y/R) was 8,983 g/r which is less than the maximum yield per recruit (9,683 g/r) that could be obtained at a fishing mortality of 0.6 year^{-1}. Generally, at all values of length at first capture, the yield per recruit increased with the increase of fishing mortality, reaching a maximum value followed by an obvious decline. Increasing the value of length at first capture made an increase in yield per recruit at all levels of fishing mortality (Fig. 5). Also, with increasing the value of length at first capture, the maximum yield per recruit was achieved at higher level of fishing mortality.
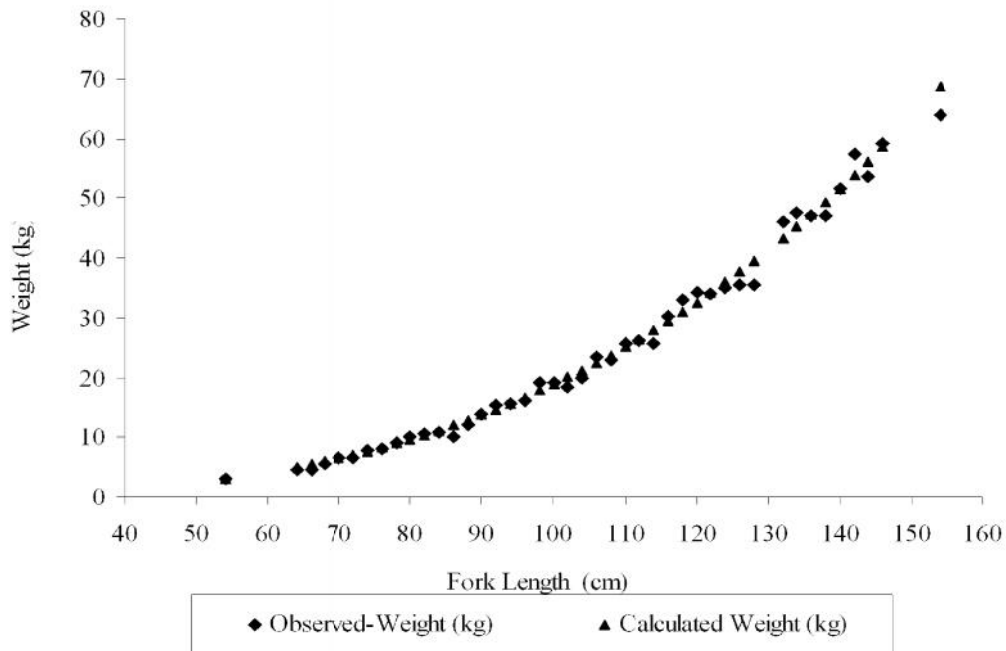
Fig. 3. Length-weight relationshipof yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.

Mortality

Figure 4 represents the length converted catch curve from which total mortality (Z) was estimated as 1.72 year^{-1}. Natural mortality (M) was estimated independently as M=0.53 year^{-1} and fishing mortality F= 1.19 year^{-1}.
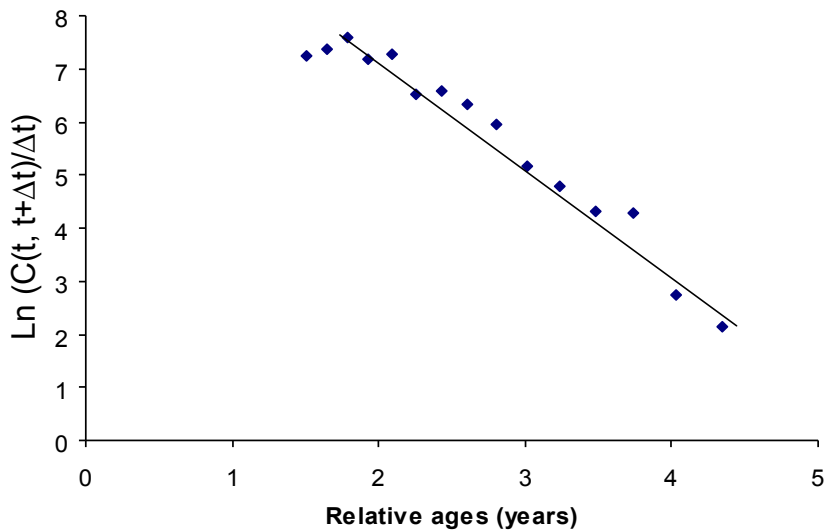

Fig.4. Linearised catch curve for estimation of total mortality rate of yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.
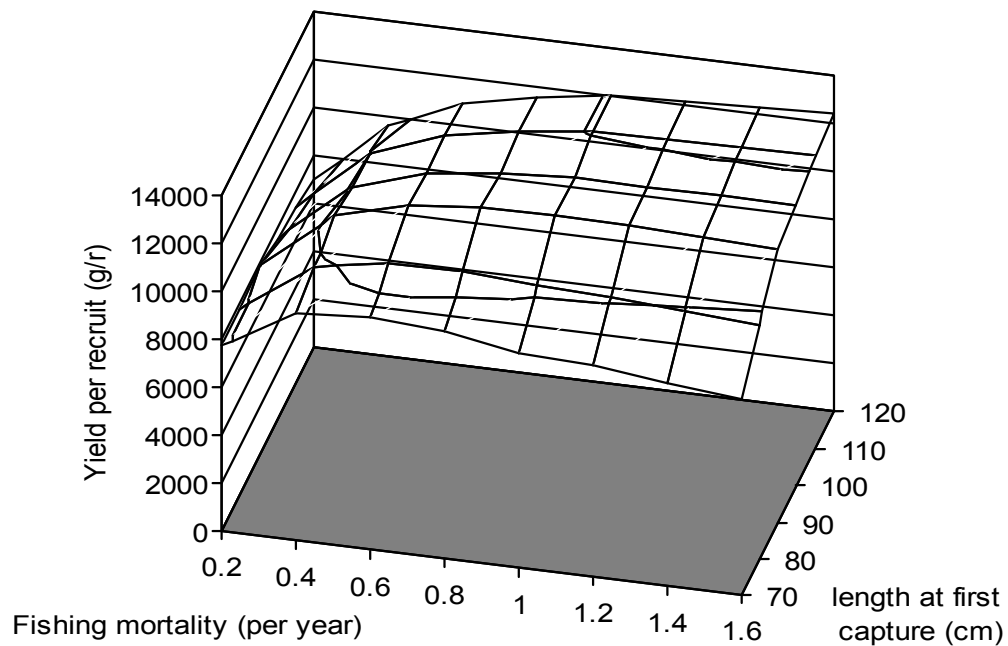
Fig. 5. Yield per recruit (g/r) for yellowfin tuna at different values of fishing mortality of yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.

A decrease of biomass per recruit (B/R) with the increase in fishing mortality is shown in Fig. 6. At the current level of fishing mortality and length at first capture the biomass per recruit (7,408 g/r) equaled to about 10% of the virgin biomass (unexploited level) which was computed as 75,766 g/r.

Discussion

Yellowfin tuna taken by the artisanal fishery included five age groups with corresponding lengths of 69.67, 110.5, 132.5, 148.28 and 159.58 cm respectively. However, it cannot be concluded that the length of 69.67 cm is corresponding to 1 year old fish, but may also correspond to 2 year old fish, because the fish sampled were always above 40 cm in length, which was reported to be corresponding to 1 year old, by a number of authors. For example, Govindraj et al. (2000) estimated the spawning season of yellowfin tuna in Omani waters, and reported that the juveniles migrate towards the coastal waters off the Arabian Sea and Gulf of Oman, when they reach the pre-adult age (60-80 cm at age 1.5-2 years). On the other hand, Al-mamry (1996) found that, the lengths of yellowfin tuna in the same area were as 78.42, 108.12, 130.1, 146.42, and 158.49 cm, at ages I, II, III, IV and V years, respectively.
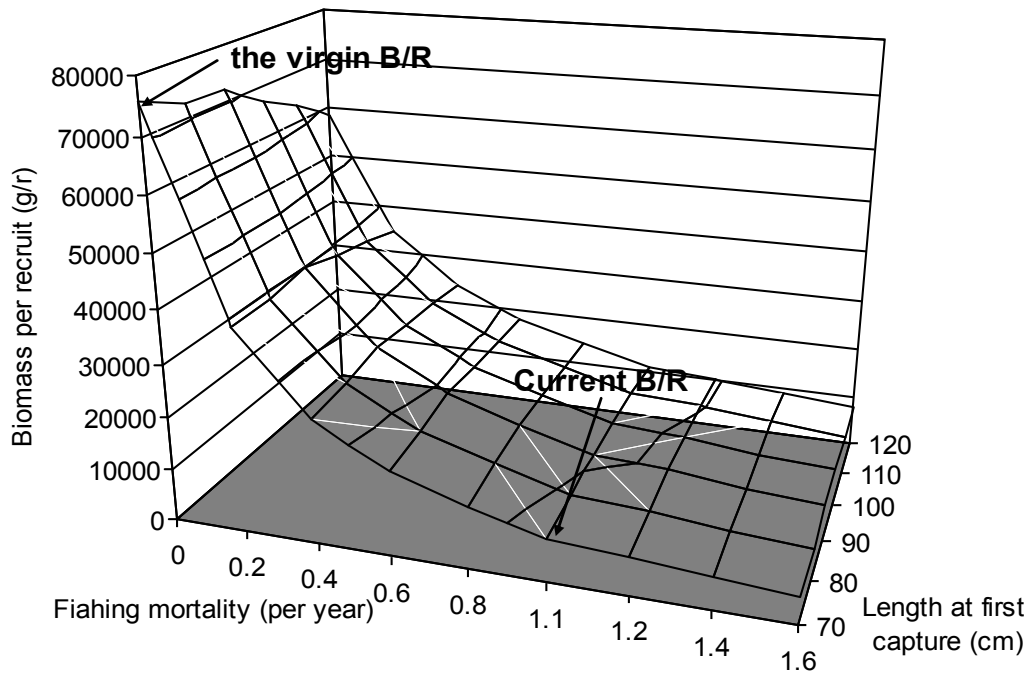
Fig. 6. Biomass per recruit (g/r) at different values of fishing mortalityof yellowfin tuna captured by the artisanal fishery of Al-Sharqiya during the fishing season from January to December 2007.

At low fishing mortality levels, increasing the value of length at first capture caused an increase in the biomass per recruit, showing a peak point after which the biomass decreases. This peak disappeared at higher levels of fishing mortality, at which the B/R would increase by increasing the length at first capture through increasing the mesh size of gillnet.

Length frequency analysis showed that young tuna dominated the catch, since fish less than 100 cm in length constituted more than 60% of the total catch. This size may indicate a state of overfishing, because other previous studies indicated that size at maturity of yellowfin tuna was over 100 cm fork length (Timochina and Romanov 1991; Maldeniya and Joseph 1988; Hassani and Stequert 1990).

The present results showed that, L_∞ was 188.2 cm, K was 0.33 $year^{-1}$ and t_o was -0.66 year. These values are in close agreement with the values reported on the same species in different geographical areas. Al-mamry (1996) found that the values of growth parameters were: K=0.42 $year^{-1}$, L_∞=189 cm, and t_o=-0.66 year for the same species in Omani waters. These values were close to findings of other studies on yellowfin tuna in different localities, including the Indian Ocean, using similar techniques. Maldeniya and Joseph (1988) estimated the growth parameters of the yellowfin tuna species in Sir Lanka and reported the L_∞ and K as 178 cm, 0.47 $year^{-1}$, respectively. Pillai et al. (1991) estimated the growth parameters with the data from gillnet fishing in the West-IndianOcean, wherethe values obtainedwere: $L_{\infty=}$171 cm, K=0.37 $year^{-1}$ and t_o=-0.4 year. Yesaki (1991) reported also that L_∞=193.9 cm, K=0.33 $year^{-1}$ and t_o=-0.17 year. Sudarsan et al. (1991)

found also that the growth parameters in the same place were: L_∞= 175 cm and K = 0.29 year^{-1}. Kayamaram (1999) analysed length frequency data in the northern coastal waters of the Oman Sea and the Arabian Gulf, the growth parameters estimated were K=0.42 year^{-1}, L_∞=196 cm, and t_o=-0.38 year.

The values of the constants a and b calculated from the length-weight relationship of yellowfin tuna in the present study were 0.0000196 and 2.99 respectively, indicating an isometric length weight relationship. Similarly, isometric growth has been reported on yellowfin tuna in the Arabian Sea (Silas et al. 1985; John and Reddy 1989; Sudarsan et al. 1991), and the Indian Ocean (Pillai et al. 1993; Stequert et al. 1996; Govindraj et al. 2000) where the value of the slope "b" ranged from 2.74 to 3.03. This may suggest an insignificant difference in the length-weight relationship of the stocks occurring in different sectors of the Indian Ocean.

The present study revealed natural mortality (M) was 0.427 year^{-1}. Several authors studied the natural mortality coefficients in different parts of the Indian Ocean (John and Reddy 1989;Pillai et al. 1991; Silas et al. 1985; John 1995; Kayamaram 1999). The estimates of M obtained from these studies ranged from 0.52 to 0.74 year^{-1}.It is clear that natural mortality in the present study is less than that reported in the above mentioned studies. This may have been attributed to the size range of the sample-at age, since the natural mortality is assumed to be higher for juveniles than for adults (Govindraj etal. 2000). According to Wilson et al. (2008) juveniles of yellowfin tuna in the Indian Ocean are heavily caught by purse seine. This may affect the estimated values of natural mortality.

The present values of total mortality (1.53 year^{-1}) and fishing mortality (1.19 year^{-1}) were less than the values found in previous study on yellowfin tuna in Oman Seas (Kayamaram et al. 2000). They showed that total and fishing mortalities were 1.85 year^{-1}and 1.25 year^{-1} respectively. There were no further definite estimations recorded for fishing mortality of yellowfin tuna in the Indian Ocean. However, Wilson et al. (2008) reported that fishing mortality exceeded the value (1.29 year^{-1}), which corresponded to (F_{MSY}) for the same species in the Indian Ocean. This was supported by a report issued by the Indian Ocean Tuna Commission (IOTC 2010).

The present study adopted the per recruit analysis to identify options for the evaluation and management of the yellowfin tuna stock, depending on the status of both biomass per recruit and yield per recruit, as a function of fishing mortality. This should help to induce a change in the value of age at first capture. Because this species is mostly caught before reaching age at first maturity, it is expected that changing mesh size of the net may improve the stock status.

At the present level of fishing mortality (1.19 year^{-1}) the corresponding Y/R was equal to 8,983 g/r. By reducing fishing mortality to 0.6 year^{-1}, the yield per recruit would increase to 9,683 g/r as a maximum value, indicating occurrence of overfishing according to Wilson et al. (2008) who reported that fishing mortality to which yellowfin tuna is exposed to in the Indian Ocean exceeds the FMSY. Moreover, according to the Indian Ocean Tuna Commission (IOTC 2010) it was assured

that fishing mortality exceeds F_{MSY}. At all values of length at first capture the yield per recruit increased with the increase of fishing mortality reaching a maximum value followed by obvious decline. Increasing the value of length at first capture led to an increase in yield per recruit at all levels of fishing mortality.

The present study shows that the change in yield per recruit is more sensitive to the change in fishing mortality (F) and length at first capture (L_c) than natural mortality (M). Thus, the change (increase) of the length at first capture of yellowfin tuna would be an effective strategy for improvement and sustainability of fish stocks. In support, Bayliff et al. (1991) suggested that the increase of the age at entry into the fishery (length increase) would maximise the overall yield per recruit of bluefin tuna, *Thunnus thynnus* (Linnaeus 1758)). Similar findings were reported by Miyabe (1991) for the bigeye tuna, *Thunnus obesus* (Lowe 1839) in the Pacific Ocean, where the yield per recruit increased with the change of fishing mortality.

At the current level of fishing mortality and length at first capture, the biomass per recruit of yellowfin tuna in the present study was equal to about 10% of the virgin biomass, which indicated over exploitation. There is some evidence of overfishing. Firstly, the value of length at first capture (69.8 cm) was less than the length at first maturity, which ranges from 100 to 120 cm (Maldeniya and Joseph 1987; Hassani and Stequert 1987; Timochina and Romanov 1991). This suggests that these fish are caught before reaching maturity. The proportion of fish taken before reaching maturity in relation to the total catch was about 67% considering length at first maturity equals 100 cm or 89% considering length at first maturity equals to 120 cm. Secondly, the increase in both yield per recruit and biomass per recruit with simulating increase of the length at first capture reveals that the enlargement of mesh size of gillnet, allows the small fish to grow to larger sizes than the size at maturity, which may be a solution for the problem of growth overfishing (Pauly, 1988).

It appears from the above discussion that an increase in mesh size of the gillnets used by the yellowfin tuna fishery may have a positive effect on the tuna stock in Omani waters.Thus the current mesh size (15 cm) should be increased to bigger size corresponding to a length at first capture ranging from 100-120 cm or more to avoid catching fish before reaching length at first maturity. Unfortunately we could not do this in the current study because of the missing data on gill net selectivity.This increase would allow the small fish that migrate from the open ocean to Omani waters for feeding and growth (John 1995; John et al. 1998; Govindraj et al. 2000) to reach maturity, and migrate back to the open ocean to spawn. This would result in more recruitment to the stock, leading to increasing the biomass. Thus increasing mesh size could be tested in later studies as a management technical measure for yellowfin tuna in Omani waters.

Conclusion

In conclusion, yellowfin tuna in Omani waters is exposed to a high level of fishing mortality which exceeds $F_{MSY/R}$, catching large numbers of small individuals, indicating obvious growth

overfishing.The present study suggests that this problem could be managed by controlling age at first capture through changing the mesh size of gill nets, which is the main fishing gear used to catch the studied species in the studied area.

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