# Yield and Biomass-per-recruit Analysis of Tiger Tooth Croaker (*Otolithes ruber*) in the Northwest of the Persian Gulf

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## Abstract

Effects of age at first capture ($t_c$) and fishing (F) as well as natural mortalities (M) on yield and biomass-per-recruit of tiger tooth croacker, *Otolithes ruber* were evaluated in the northwest of the Persian Gulf using the Beverton-Holt model. The yield-per-recruit (Y/R) was 175 (g/r), which was less than maximum yield-per-recruit value (217 (g/r)) at fishing mortality of 1 year$^{-1}$. Current F ($F_{CUR}$) was estimated to be lower than the level that produced maximum potential yield-per-recruit ($F_{MAX}$) at all scenarios of tc and M=0.50. Increases in yield from $F_{cur}$ to $F_{max}$ ranged from 4.3% to 36.4%, depending on the level of M and tc used in the model. However, this relatively small gain in yield corresponded to an increase in F of 471.58%. The biomass-per-recruit (B/R) decreased rapidly with increasing values of F and the trend in all scenarios of $t_c$ was similar with minor differences. The B/R represented about 65% of the virgin biomass and current fishing mortality rate ($F_{cur}$) was less than the $F_{max}$ and it was near the $F_{0.1}$, indicating that *O. ruber* was slightly under exploited. $F_{cur}$ (0.44) in estimated population was well lower than the $F_{max}$ (1) and it was close to $F_{0.1}$ (0.5).

Keywords: *Yield-per-recruit model, Fisheries management, Otolithes ruber, Biological reference point.*

## 1. Introduction

Yield-per-recruit models are frequently used to determine an important biological reference parameter $F_{0.1}$, a fishing mortality rate at which the rate of increase in yield-per-recruit is 10% of that, when F = 0 (Deriso 1987; Hilborn and Walters, 1992). These parameters have been used managing many fisheries in the world (Hilborn and Walters, 1992) and evaluating the status of fisheries. Yield-per-recruit depends on the growth rates of individual fish, natural mortality and fishing mortality. The fishing mortality rate that achieves a maximum yield-per-recruit is

called $F_{max}$. However, $F_{max}$ is often greater than FMSY and can lead to unsustainable harvest levels and an anti-conservative fishing mortality threshold. Much of this is due to the fact that $F_{max}$ does not take the reproductive viability of the remaining stock into account. When the fishing mortality rate does exceed $F_{max}$, it is called growth overfishing.

*O. ruber* is a highly valuable commercial species in Iran, ranking 9th most landed demersal fish species during 2011-2012. In the northwest of the Persian Gulf, this species is even more important (3th place in 2011-2012). Total commercial catches of *O. ruber* in Iran and Khuzestan have been in a steady state for the last 10 years (2003–2012) with average landings of 6517 and 3016 tons per year, respectively (IFO

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Statistics, 2012).

There have been few studies published on stock assessment of *O. ruber*. Population dynamic parameters have been studied in the Persian Gulf by Niamaimandi et al. (2003), Khodadadi et al. (2010), Kamali et al. (2006) and Eskandari et al. (2012). Other population dynamic study has been done in the Philippines by Navaluna (1982).

Yield-per-recruit and biomass-per-recruit analyses were performed for tiger tooth croaker as part of stock assessment study of the tiger tooth croaker in the northwest of the Persian Gulf. Objectives of this study were to evaluate the effect of fishing and natural mortalities and administered policies on tiger tooth croaker yield-per-recruit and to discuss implications for managing of tiger tooth croaker.

## 2. Materials and Methods

Calculation of yield from a given recruitment is important in many stocks, when stock and recruitment relationship is unknown or recruitment is highly variable. Because, variation in recruitment is ignored, yield is expressed as the accumulated amount of yield produced by a given fishing mortality for one recruited fish in its whole life span (Zhang, 1999). To calculate yield-per-recruit, values of the parameters used in this study are given in Table 1.

Yield-per-recruit curves were calculated for three different sizes at first capture ($t_c$) using the Beverton-Holt yield-per-recruit model (Beverton and Holt, 1957):

$$Y/R = Fe^{[-M(t_c-t_r)]} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c-t_o)}}{F + M + nK}$$

and biomass-per-recruit was calculated using the following equation derived by Beverton and Holt (1975):

$$B/R = e^{[-M(t_c-t_r)]} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c-t_o)}}{F + M + nK}$$

Where Y/R = yield-per-recruit in weight (g);

B/R = biomass-per-recruit in weight (g);

F = fishing mortality coefficient;

M= natural mortality coefficient;

$W_{oo}$ = asymptotic weight (von Bertalanffy growth parameter);

$U_n$ = summation parameter ($U_o$=l, $U_1$=-3, $U_2$=3, $U_3$=-1);

$t_c$ = mean age at first capture;

$t_r$ = mean age (years) at recruitment to the fishing area;

$t_o$ = hypothetical age at which fish would have been zero length (von Bertalanffy growth parameter);

To see how yield-per-recruit varied with rate of fishing and age of first capture, we calculated yield-per-recruit by varying M (0.5, 0.56, and 0.62), F and $t_c$ (1.46, 1.55, 1.95). Two biological reference points $F_{0.1}$ and $F_{max}$ were calculated using age-structured yield-per-recruit models. $F_{max}$ corresponds to the highest value of Y/R and $F_{0.1}$ was determined numerically by finding the F at which the slope of the Y/R curve was 10% of the slope at the origin.

Table 1. Parameter estimates used in this study. Data from Eskandari (2012)

| Parameter | Estimated value |
|---|---|
| $W_\infty$ | 3434(g) |
| $M$ | 0.56 (/y) |
| $K$ | 0.27 (/y) |
| $a$ | 0.005 |
| $b$ | 3.19 |
| $L_r$ | 22 (cm) |
| $L_c$ | 27 (cm) |
| $t_r$ | 1.03 (y) |
| $t_c$ | 1.46 (y) |
| $t_0$ | -0.43 (y) |
| $t_{max}$ | 10.68 (y) |
| $F_{current}$ | 0.44 (/y) |

To test the sensitivity of the model, three different scenarios were set up, considering the estimated M=0.5, M=0.56 and M=0.62. An Excel spreadsheet was used to calculate Y/R and B/R for a range of F-values, which produced a Y/R and B/R curve as a function of F.

## 3. Results

The relative yield-per-recruit curve (Y/R) is shown in Figure 1. $F_{cur}$ (0.44) in estimated population was lower than the $F_{max}$ (1) and closer to $F_{0.1}$ (0.5). The observed Y/R (175 g/r) was lower than Y/R at $F_{max}$. The biomass-per-recruit (B/R) represented about 65% of the virgin biomass. The Y/R and B/R increased rapidly in the range of F between 0 and 1 and gradually decreased after that (Fig. 1).
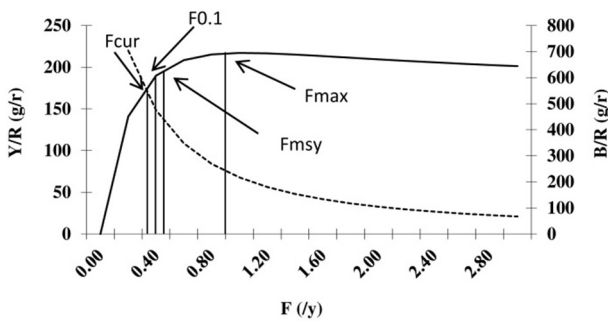


Fig. 1: *O. ruber* yield-per-recruit (Y/R) and biomass-per-recruit (B/R) estimated for natural mortality (M=0.56) and age-at-capture ($t_c$ =1.46) in the northwest of the Persian Gulf (2009)

The Y/R response to different values of M (instantaneous natural mortality) and tc are shown in Figures 2, 3 and 4. Y/R increased rapidly at low values of F over most of the range tc. $F_{cur}$ values were lower than $F_{max}$ and $F_{0.1}$. In all scenarios of $t_c$, maximum Y/R was in M=0.5 and $F_{max}$ 0.8-2.4 which was higher than the observed $F_{cur}$.
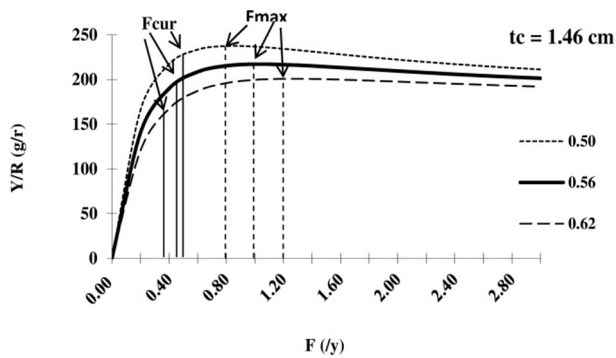


Fig. 2: Curves of yield-per-recruit for *O. ruber*, giving three different scenarios of M-values and age-at-capture ($t_c$ =1.46) in the northwest of the Persian Gulf (2009)
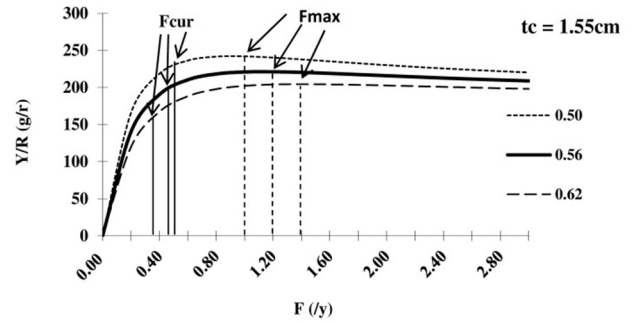


Fig. 3: Curves of yield-per-recruit for *O. ruber*, giving three different scenarios of M-values and age-at-capture ($t_c$ =1.55) in the northwest of the Persian Gulf (2009)
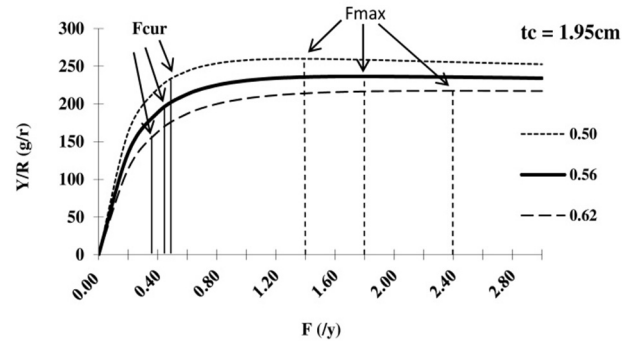


Fig. 4: Curves of yield-per-recruit for *O. ruber*, giving three different scenarios of M-values and age-at-capture ($t_c$ =1.95) in the northwest of the Persian Gulf (2009)

Y/R against fishing mortality for three arbitrary values of age at first capture ($t_c$) are shown in Figure 5. In all scenarios of $t_c$=1.46, 1.55 and 1.95, maximum Y/R reached a plateau at $F_{max}$ which were higher than the observed $F_{cur}$.
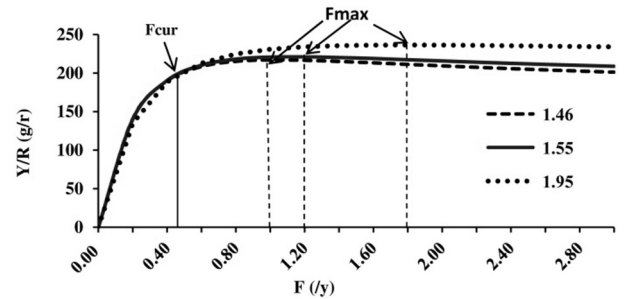


Fig. 5: Curves of yield-per-recruit for *O. ruber*, giving three different scenarios of age-at-capture ($t_c$) and M-values (M=0.56) in the northwest of the Persian Gulf (2009)

Estimated values of Y/R with $F_{cur}$ at all arbitrary

levels of (M) were lower than the maximum potential of Y/R ($F_{max}$). Over the range of $F_{cur}$ to $F_{max}$ at different levels on M and $t_c$, the Y/R increased approximately 30% (Table 2). However, this occurred at high levels of F. The B/R was shown to decline rapidly with increasing F at different levels of $t_c$ and despite slight differences, the overall trend was similar (Fig. 6).
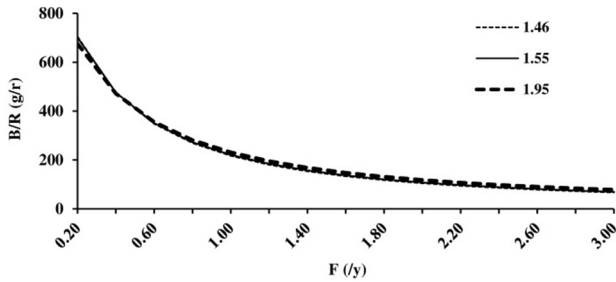


Fig. 6: Curves of biomass-per-recruit for *O. ruber*, giving three different scenarios of age-at-capture ($t_c$) and M-values (M=0.56) in the northwest of the Persian Gulf (2009)

Table 2: Percent increase in yield-per-recruit of *O. ruber* from $F_{cur}$ to $F_{max}$ in the northwest of the Persian Gulf in 2009

| M | | $F_{cur}$ | $F_{max}$ | Y/R increase% | F increase% |
|---|------|--------|--------|-------|--------|
| | 0.50 | 227.60 | 237.40 | 4.30 | 60.00 |
| 1.46 | 0.56 | 195.20 | 217.00 | 11.20 | 127.00 |
| | 0.62 | 164.30 | 200.70 | 22.15 | 215.78 |
| | 0.50 | 229.70 | 241.80 | 5.26 | 100.00 |
| 1.55 | 0.56 | 195.90 | 221.10 | 12.86 | 172.72 |
| | 0.62 | 164.00 | 204.40 | 24.63 | 268.42 |
| | 0.50 | 234.10 | 259.80 | 10.97 | 180.00 |
| 1.95 | 0.56 | 195.00 | 236.50 | 21.28 | 309.00 |
| | 0.62 | 159.30 | 217.30 | 36.41 | 531.58 |

Isopleths describing the response of Y/R and B/R to different values of F and tc are shown in Figures 7 and 8. The Y/R response showed that maximum Y/R reached at $t_c$=3 for M=0.5 while for both M=0.56 and 0.62 it was at tc =2.5. The B/R decreased rapidly as F increased and maximum B/R for all natural mortalities (M=0.5, 0.56, 0.62) was at $t_c$=2.5.
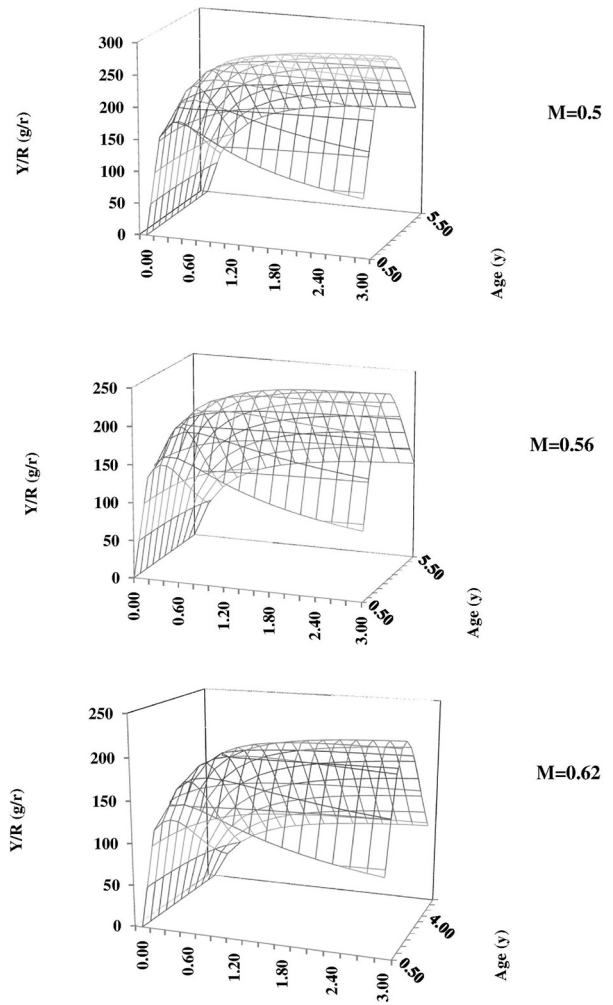


Fig. 7: Isopleth diagrams of yield-per-recruit for *O. ruber*, giving different scenarios of fishing mortality (F) and age-at-capture ($t_c$) where M=0.5, 0.56 and 0.62 in the northwest of the Persian Gulf (2009).

## 4. Discussion

Generally, Y/R model has been used to assess growth overfishing. The model estimates the Y/R for various fisheries activities (fishing mortality and fish size), describes the current usage of the stock and suggests policies to enhance the yield.

The Y/R analyses for three different ages at first capture (1.46, 1.55, 1.95 years) and natural mortality (0.50, 0.56, and 0.62) showed that overfishing had not occurred and fishing effort could be increased to achieve the maximum sustainable yield. However, in order to achieve the maximum point, the Y/R must be

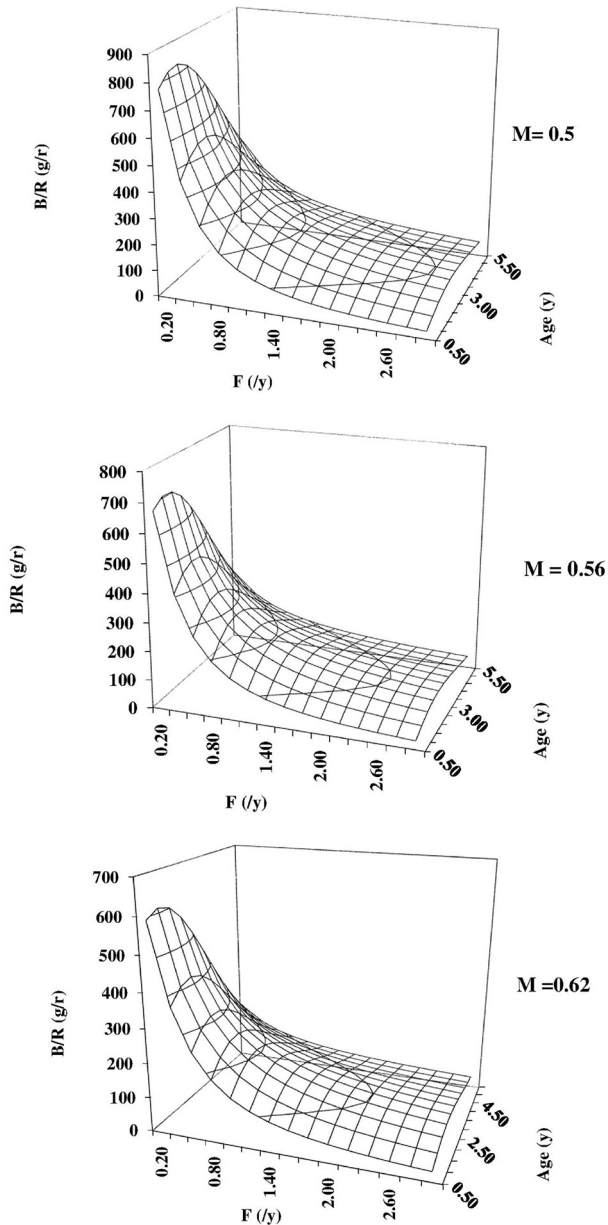increased from 4 to 36% and fishing mortality from 60 to 532% (Table. 2).



Fig. 8: Isopleth diagrams of biomass-per-recruit for *O. ruber*, giving different scenarios of fishing mortality (F) and age-at-capture ($t_c$) where M=0.5, 0.56 and 0.62 in the northwest of the Persian Gulf (2009)

Therefore, increasing fishing effort for multiple times to reach the maximum point is not reasonable and therefore, it is not recommended. The Beverton and Holt model of Y/R indicated that the stock of Brycon microlepis in the Cuiabá River Basin was not overfished (Mateus and Estupinan, 2002). They suggested that many unknown important factors interfered with recruitment; therefore, some caution is necessary in applying this approach.

Grandcourt et al. (2005) and Farmer et al. (2005) detected growth overfishing of *Argyrosomus japonicus* and *Epinephelus coioides* by Y/R analysis based on higher value of $F_{cur}$ than $F_{0.1}$ and $F_{max}$. In the present study, $F_{cur}$ was lower than $F_{0.1}$ and $F_{max}$. The use of Y/R models might be particularly restrictive for fast growing tropical species with high rates of natural mortality as the curves may not reach a maximum within a reasonable range of fishing mortality values (Gayanilo and Pauly, 1997). Therefore, this model was suitable for long-lived species and may be limited for short or moderate-lived species.

Maximum Y/R was obtained at $t_c$ =1.95 for the range of M used in our study and highest value of Y/R was always estimated at M=0.5 for all scenarios of tc (Figs. 2, 3, 4, 5). Isopleths curve view showed that increasing tc and fishing mortality provided more yield at three different natural mortalities. The maximum Y/R in isopleths curve view was obtained at $t_c$ =2.5 - 3 (Figs. 7, 8, 9). As a result, increased length or age at first capture in fishery policies should be implemented for achieving greater yield. However, the biological reference points in this model were lower than the current situation. Therefore, catching bigger fishes than length at maturity is recommended for increasing Y/R because 20% of the yield in numbers consisted of fish that were smaller in size at first sexual maturity (Eskandari et al., 2012).

This was particularly important given that 29% of the yield in numbers consisted of fish that were below the size at first sexual maturity. If fish were retained by traps at the size at which yield-per-recruit would be maximized they would have had a chance to spawn 2–3 times before reaching the mean size at first capture (Grandcourt et al., 2005).

Emami (2006) obtained maximum yield per recruit with fishing mortality lower than $F_{cur}$ and suggested that in 2005, growth overfishing occurred for *O.ruber*.

In this study, the B/R represented about 65% of virgin biomass, and since current F for this species in the exploited areas studied, was lower than $F_{max}$ and was close to $F_{0.1}$, it could be argued that the stock was not over-exploited. The slight differences of B/R at three scenarios of tc (Fig. 6) indicated that the impact of age at capture on the biomass-per-recruit was very small for *O. ruber*.

## Acknowledgments

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