Iranian Journal of Fisheries Sciences 20(2) 463-474 2021
DOI: 10.22092/ijfs.2021.123867

Research Article

The decline in the size of ribbonfish, *Trichiurus lepturus* (Linnaeus 1758), over the past decade in the Persian Gulf

Khadem Khervi F[1]; Ghodrati Shojaei M.[1*]; Taghavimotlagh S.A[2].

Received: December 2019 Accepted: February 2020

Abstract

Size-dependent variation in growth, mortality, and recruitment over time are potentially controlled by changes in length -frequency distribution that is dependent to capture probability. The changes in the length-frequency distribution of ribbonfish, *Trichiurus lepturus* were studied along northern coasts of the Persian Gulf during the period 2008-2017. The length-frequency distribution of ribbonfish indicated the exploitation of larger sizes over the past decade. The mean total length was significantly smaller than the mean length recorded a decade earlier in 2008 (p<0.05). The length-weight relationship (W_T=0.00004$L_T^{3.44}$) was found to be significant at 1% level of significance and indicated positive allometric growth. The Von Bertalanffy growth parameters of all fish were L_∞ =119.35 cm, K=0.3 year^{-1}, and t_0 = -0.38 year. Total, natural, and fishing mortality were estimated as 1.16 year^{-1}, 0.53 year^{-1}, and 0.63 year^{-1}. The annual instantaneous rate of fishing mortality was higher than the target (F_{opt}= 0.26 year^{-1}) and limit (F_{lim}=0.35 year^{-1}) reference points, indicating that the ribbonfish stock is at the risk of unsustainable exploitation.

Keywords: *Trichiurus lepturus*, Size decline, Population dynamics, Persian Gulf

1-Department of Marine Biology, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, 4641776489, Noor, Iran.
2-Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran
[*]Corresponding author's Email: mshojaei@modares.ac.ir

Introduction

Ribbonfish, *Trichiurus lepturus* (Linnaeus, 1758) belongs to the family Trichiuridae, has a silvery ribbon-like body, which is strongly elongated and compressed. *T. lepturus* is distributed throughout the tropical and temperate waters, mainly between latitudes 60°N and 45°S (Froese and Pauly, 1996). The ribbonfish is not marketed in Iran, but there is a high demand for export to the East Asia and thus has been increasingly targeted by both artisanal and commercial sectors (Taghavimotlagh and Shojaei, 2018). The total catch of the fish has increased by 20 times in recent years on the northern coast of the Persian Gulf and Oman Sea. The catch reached from 2281 tons in 2006 to 47574 tons in 2016. The proportion of ribbonfish catch in the Iranian EEZ compared to the total catch increased from % 0.8 in 2006 to %7.9 in 2016 (Taghavimotlagh and Shojaei, 2018). The increased fishing effort has caused the risk of resource depletion in the past decade. Intensive fishing activities without considering the environmental limits may threaten the sustainable exploitation of marine resources (Taghavimotlagh *et al*., 2021). The study of the growth parameters and mortality rates of fish populations provides vital information on exploration rate, which ensures the sustainability of the stocks (King, 2013). There are many studies documenting the population characteristics of ribbonfish around the world (Ghosh *et al*., 2009; Memon *et al*., 2016; Liang and Pauly, 2017; Taghavimotlagh and Shojaei, 2018). However, to our knowledge, little information is available in the Persian Gulf.

At the population level, fishing can change the age and size structure and decrease abundance, biomass, and mean size (Nicholson and Jennings, 2004). Along with the historical size changes, the study of the dynamics of the populations improves the ability to understand the status of the stock and support fishing management plans. The growth parameters and mortality rates are important input data in many population models. These parameters need to be calculated using different integration methods and additional data sources. Generally, two main methods are used to estimate the fish growth rates, including hard part proxies (otoliths and scale) and/or length-frequency data (Anderson *et al*., 1992). The first method is usually used when the annual rings are visible in hard parts and mainly is applicable in temperate regions. By contrast, in tropical regions, annual rings are not formed due to constant water temperature, and thus, the latter should be applied (Liang and Pauly, 2017).

We compared the size distribution of ribbonfish with a decade ago when we studied the catch per unit of area and the by-catch composition of midwater trawls in the Persian Gulf (Shojaei and Taghavimotlagh, 2011). The midwater trawlers still operate preferentially in the Oman Sea. However, they are also allowed to fish in the Persian Gulf for a few months. Additionally, we estimate the growth parameters and mortality rates of the fish using length-frequency data. The results could be beneficial in the successful implementation of fisheries management plans or led to the formulation of a new set of regulations, such as temporary closures of fisheries in the Persian Gulf.

Materials and methods

The monthly length-frequency data were obtained to estimate the size distribution, growth parameters and mortality rates of *T. lepturus* in the Persian Gulf. In total, 1826 individuals were collected randomly at several landing sites from April 2017 to March 2018 (Fig. 1).

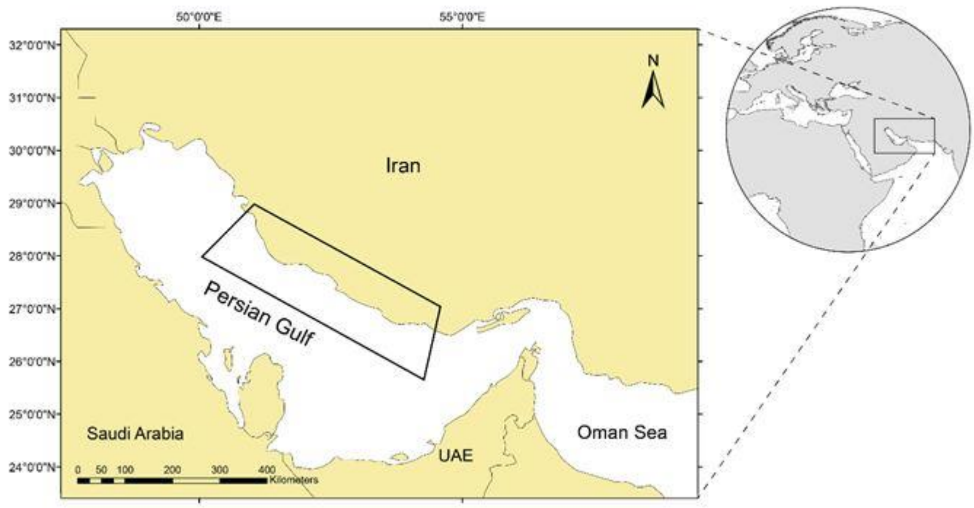

Figure 1: Sampling location for *T. lepturus* in the Persian Gulf, Iran, April 2017– March 2018.

Three fishing gears were used to catch the specimens, including trawl nets (54%), drift gillnet (12%), and hand line (34%). Total length (LT) and anal length (LA) of individual fishes were measured to the nearest cm and total weight (W_T) to the nearest 0.1 g whenever possible. The linear regression model (L_T = a+bL_A) was used to determine the relationship between total and anal length. The length-weight relationship was calculated by a conventional equation $W_T = a.L_T^b$. This equation log-transformed to a linear model (W_T = log a + b×log L_T), where a is the intercept of the regression curve, and b is the regression coefficient indicating isometric growth when close to three (Froese, 2006). The t-test was used to determine any significant deviation of the b value from the theoretical isometric value (Snedecor and Cochran, 1967). The analysis of variance (ANOVA) followed post hoc comparison by the Tukey test (Significance level of $p<0.05$) was used to compare the mean total length of the ribbonfish among months. In order to track the changes in size distribution of ribbonfish, we compared the size frequency distribution of the fish in the current study with the data collected a decade ago when we studied the catch per unit of area and the by-catch composition of midwater trawls in the Persian Gulf (Taghavimotlagh *et al*., 2011). Statistical analyses were performed using the R (R Core Team, 2017).

The von Bertalanffy growth function (VBGF) was used to evaluate the infinitive length (L_∞) and growth coefficient (K) of the T. *lepturus*. The VBGF is defined as:

$L_t = L_\infty(1 - e^{K(t-t_0)})$

Where L_∞ is the asymptotic length, *i.e.*, the mean length that the fish of a given stock would reach if they were able to grow indefinitely; K is the growth coefficient, and t_0 is the time at which the length is equal to zero. The value of t_0 calculated using Pauly's empirical equation (Pauly, 1980):

$$Log_{10}\,(-t_0) = -0.3922 - 0.275\,log_{10}\,L_\infty - 1.0381\,log_{10}\,K$$

The growth performance index (φ') was obtained using the following equation (Pauly and Munro, 1984).

$\varphi' = \log K + 2\log L_\infty$

Fishing mortality was calculated using the length converted catch curve method (Pauly, 1983). Additionally, the Pauly's (1980) empirical equation was applied to estimate the natural mortality (M) index:

$$Log10\,(M) = -0.0066 - 0.276\,log10\,(L\infty) + 0.6543\,log10\,(K) + 0.4634\,log10\,(T)$$

Where *T* was the annual mean of sea surface temperature (*i.e.*, 26.5°C in the Persian Gulf). Following the calculation of Z and M, fishing mortality (F) and exploitation rate (E) estimated using the functions; $F = Z - M$, and $E = F/Z$. In line with the exploitation rate, the stock status was also assessed by comparing the fishing mortality rate with the target (F_{opt}) and limit (F_{lim}) biological reference points defined as F_{opt}=0.5 M and F_{lim}=2/3 M (Patterson, 1992). The TropFishR package available in R software was used to estimate the growth and mortality rates from length-frequency data (R Core Team, 2017).

Results

The size of sampled fish ranges from 10 to 113 cm total length with the mean (±SD) value of 67.35±17.26 cm (Fig. 2). The minimum and maximum length was recorded in April and January with the mean length of 50.71 and 77.4 cm, respectively (Table 1). There was no significant difference among monthly mean length of specimens in the Persian Gulf (p>0.05). Results on the total length and anal length relationship showed a significant linear model for the ribbonfish in the Persian Gulf (Fig. 3; R^2=0.97; p<0.01). In the present study, the b value was estimated as 3.64. The length-weight relationship for

T. lepturus found to be significant at 1% level of significance (Fig. 4; R^2=0.94; p<0.01).

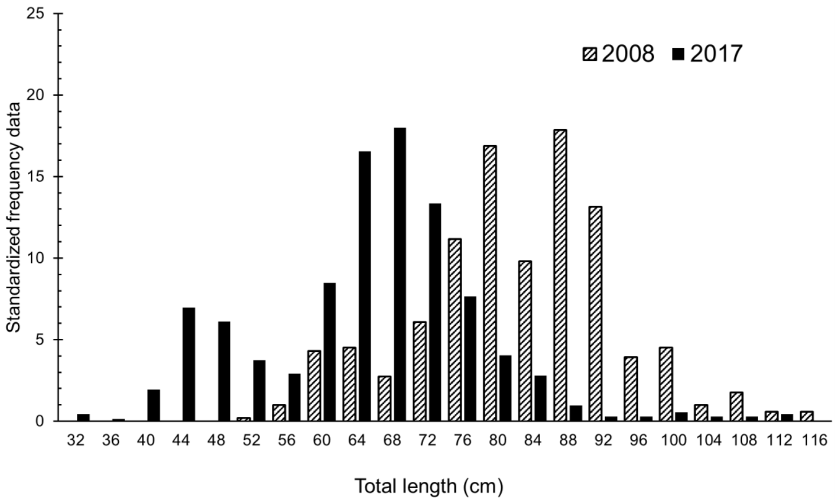

Figure 2: Frequency distribution of different size-classes for *T. lepturus* collected from the Persian Gulf in 2008 and 2017.

Table 1: Mean length of *T. lepturus* sampled in different months in the Persian Gulf (2017-2018).

Month	Number	Total length, cm	Mean± SD
		2017	
April	187	11-95.5	50.71+23.82
May	59	62-88	69.46+4.44
June	105	50-83	61.74+7.31
July	150	15.5-81	62.35+12.27
August	175	29-109	61.55+12.04
September	190	10-113	55.7+21.07
October	150	12.5-106	61.76+14.17
November	159	38-111	67.04+10.78
December	101	64-89	75.99+5.11
		2018	
January	306	48-101	77.40±6.46
February	26	64 – 84	75.04+5.03
March	218	17-101	62.78+22.35

The results of the response surface analysis provided the best fit of growth model *i.e.*, L_∞=119.35 cm and K=0.3. These parameters later used in all the calculations. The values of t_0 and φ' were estimated as -0.38 year, and 3.63. The yearly growth curve of the *T. lepturus* showed that the fish attained 40.45 cm, 60.90 cm, 76.05 cm, 87.27 cm, 95.58 cm, and 101.7 cm at the ages of one to six years old, respectively (Fig. 5). The annual rate of total mortality (Z) derived from catch curve analysis was 1.16 year^{-1} (Fig. 6). The annual instantaneous rate of natural mortality (M) was estimated as 0.53. Using the value of Z and M, fishing mortality and exploitation rate (E) were calculated as 0.63 year^{-1} and 0.54 respectively. Biological reference points, *i.e.*, F_{opt} and F_{lim} were estimated as 0.26 year^{-1} and 0.35 year^{-1}, respectively. The annual instantaneous rate of fishing mortality (F=0.63 year^{-1}) was greater than the target and limit reference points, indicating that the ribbonfish stock is at the risk of unsustainable exploitation.

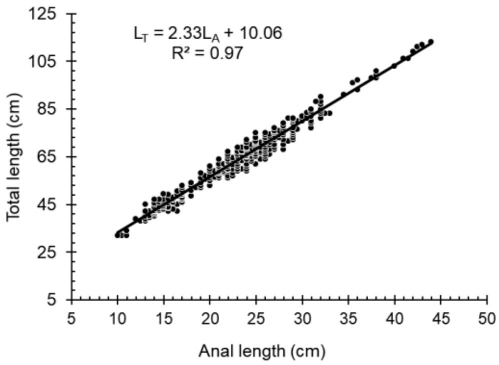

Figure 3: Relationships between total length (L_T) and anal length (L_A) of *T. lepturus* in the Persian Gulf.

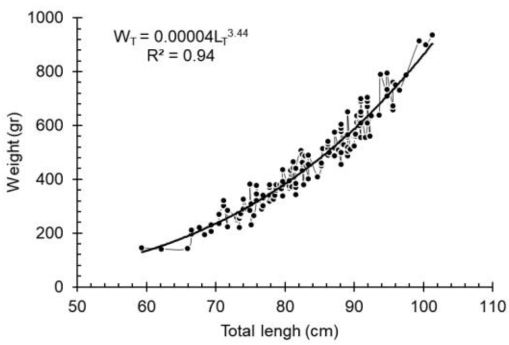

Figure 4: Relationship between total length (L_T) and weight (W_T) of *T. lepturus* in the Persian Gulf.

Figure 5: The von Bertalanffy growth curve for *T. leptutus* in the Persian Gulf.

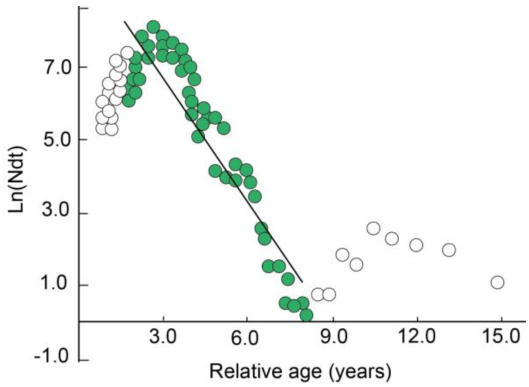

Figure 6: Length converted catch curve model for estimation of total mortality (Z) of the *T. lepturus* in the Persian Gulf.

Discussion

Higher demand for ribbonfish in recent years, together with operating improved mid-water trawl nets that catch>70 % of ribbonfish, has resulted higher catches that may lead to overexploitation. Ribbonfish trawlers conduct fishing trips for 7-15 days beyond the EEZ (Shojaei and Taghavimotlagh, 2011). Along with these vessels, traditional fishing sectors target ribbonfish using boats equipped with LEDs (low power light-emitting diode panels) to increase fish attention to the baits. The mean size of ribbonfish recorded in the present study (67.35 cm total length) was lower than that reported a decade ago (81.13 cm total length) from the same area (Taghavimotlagh *et al*., 2011). Higher marketability of large fish in line with the size-selective properties of the gears causes large fish to be over-proportionally removed from the stock. Larger fish produce more eggs and more successful offspring than smaller fish and can buffer adverse environmental conditions. However, truncation of the fish stock's size structure to the detriment of large fish can lead to magnified fluctuations of recruitment, abundance, and biomass (Anderson *et al*., 1992). The paucity of larger sizes and declining the size of harvested fish is typically taken to be a warning sign of overfishing. Given the importance of mean size as an indicator of the state of a resource, these comparisons help to provide information on exploitation patterns and can be used for conservation and management. Along with an increase in fish mortality, gear selectivity, and recruitment variability influence the mean size (Nicholson and Jennings, 2004). Presumably, rapidly developing fisheries and subsequent reduction in recruitment are likely to be the cause of the observed decline in mean size in the study area.

The results of the length-weight relationship showed that *T. lepturus* has a positive allometric growth. It agrees well with the results of (Al-Nahdi *et al*., 2009; Taghavimotlagh *et al*., 2010; Ghosh *et al*., 2014; Taghavimotlagh and Shojaei, 2018) reported from the Strait of Hormuz, the Arabian Sea and the Indian Ocean. The small variations could be related to different biological factors such as food quality, habitat, spawning season, and a length range of sampled specimens (King, 2013).

Growth parameters are essential parameters to estimate the stock size, recruitment, and mortality of the fish population (Shojaei *et al*., 2007). The values of L_∞ and K were calculated as 119.35 cm and 0.3 (year^{-1}). The growth parameters varied within the specimens that might experience different environmental conditions. Various authors reported different L_∞ for *T. lepturus* in different water bodies of the world (Table 2). Liang and Pauly (2017) reported the highest value of L_∞ for *T. lepturus* (i.e., 152.4 cm total length) in China. From work done on a fish stock in the Persian Gulf (Strait of Hormuz), Taghavimotlagh and Shojaei (2018), estimated that the L_∞ is equal to 111.3 cm L_T. Food availability and water temperature might influence the growth of fish and further affect the population's mean size (Yoneda and Wright, 2005; Hakimelahi *et al*., 2010). From data in Table 2, it can be seen that the infinitive length in the Persian Gulf is smaller than reported elsewhere. The Persian Gulf categorized as a subtropical region and usually does not undergo marked temperature cycles. The field observations indicate that the fish population size is generally small in the Persian Gulf compared to the adjacent region, mostly because of its harsh environmental conditions

(Sheppard *et al*., 2010). In the current study, the growth rate (K) was calculated as 0.3 that is nearly comparable with the research done by (Taghavimotlagh and Shojaei, 2018), but lower than those estimates (0.5 and 0.72) by Mohite and Biradar, (2001) and Abdussamad *et al* (2006). It is important to note that the environmental conditions such as temperature are practical factors in changing the growth parameters even in the same stock (King, 2013). Principally, by increasing temperature, the K value increases logarithmically, and L_∞ dwindle dramatically (Sparre and Venema, 1998). The growth performance index was 3.63 in the present study, which is comparable with many previously published reports by (Ghosh *et al.*, 2009; Avinash *et al*., 2014; Taghavimotlagh and Shojaei, 2018) in FAO 51 region (Table 2).

Table 2: Summary of growth parameters and mortality rate estimates of *T. lepturus*.

	Study area	φ'	L_∞ (cm)	K year^{-1}	t0 year	Z year^{-1}	M year^{-1}	F year^{-1}
Present study	Persian Gulf	3.63	119.35	0.3	-0.38	1.16	0.53	0.63
Taghavimotlagh and Shojaei (2018)	Persian Gulf and Oman sea	3.70	111.3	0.41	-0.28	1.11	0.67	0.44
Liang and Pauly (2017)	China's coastal seas	3.78	152.4	0.38	-	1.99	0.54	1.45
Avinash *et al*., (2014)	Veraval coast, India	3.35	131.25	0.13	-0.0777	0.44	0.31	0.13
Mohite and Biradar (2001)	Maharashtra coast, India	-	128	0.5	-0.009	2.66	0.77	1.89
Ghosh *et al*., (2009)	Veraval, India	3.71	134.1	0.29	-0.0527	1.44	0.51	0.93
Abdussamad *et al*., (2006)	Kakinada, India	-	128.2	0.72	-0.003	4.32	0.98	3.34
Reuben *et al*., (1997)	Visakhapatnam coast, India	-	106.82	0.61	-0.1399	2.41	0.89	1.52
Narasimham (1994)	Kakinada, India	-	145.4	0.29	-0.20	3.16	0.46	2.70
Chakraborty (1990)	Bombay, India	-	129.7	0.50	+0.0011	1.96	1.05	0.91

In the current study, the total mortality (Z), natural mortality (M) and fishing mortality (F) were calculated as 1.16 and 0.53 and 0.63 per year, respectively. The estimate of Z is similar to the values reported by (Taghavimotlagh and Shojaei, 2018) from the Strait of Hormuz. However, it is principally lower than those reported from India (Table 2). The reported values of natural mortality for *T. lepturus* range from 0.31 year^{-1} to 1.05 year^{-1} (Chakraborty, 1990). The decline in the mean body size, higher fishing mortality, the exploitation rate, and target and limit reference points confirm that the ribbonfish stock is under fishing pressure. Overfishing interrupts the stock from the regular recovery that guarantees the sustainable yield.

The results of the current study provide fundamental information on the dynamics of *T. lepturus* population in the Persian Gulf. Given the high fishing pressure, partial closure of the fishery for a portion of the annual spawning season would increase the abundance of breeding stock, reduce fishing mortality and ensure the long-term sustainability of the fishery. It is recommended to determine the minimum size of capture by regulating the mesh size of the nets to better protect the resources. The life-history trait patterns should be studied as a prerequisite for effective management of this commercially valuable fishery resource

Acknowledgement

We would like to acknowledge the fishermen for their support in sample collection. We also thank Ramin Vali Skandani and Ebrahim Bolkheiri for logistic support and help with fieldwork. This work has been supported by the Tarbiat Modares University and Iran National Science Foundation (Grant No. 93042400).

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