Iranian Journal of Fisheries Sciences 20(2) 298-312 2021
DOI: 10.22092/ijfs.2021.123623

Research Article

Life history traits of ribbonfish *Trichiurus lepturus* (Linnaeus, 1758) in the Persian Gulf and Oman Sea

Taghavimotlagh S.A.[1]; Ghodrati Shojaei M.[2*]; Vahabnezhad A.[1]

Received: August 2020 Accepted: December 2020

Abstract

Ribbonfish, *Trichiurus lepturus* (Linnaeus, 1758), is an important component of subsistence fisheries throughout its tropical and subtropical distribution. The catch rate of ribbonfish has increased seven-fold in a decade in the Persian Gulf and Oman Sea. We collected monthly biological samples from *T. lepturus*, to estimate growth and mortality parameters, and identify species reproductive pattern. The annual instantaneous rate of fishing mortality (0.63 $year^{-1}$) 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 overexploited. The gonado-somatic index and monthly gonadal maturity stages of harvested fishes indicated that *T. lepturus* presents continuous reproductive activity throughout the year, peaking in the four months from February to May. The size at first maturity was estimated at 70.9 cm total length for females. The overall sex ratio differed significantly from the expected 0.5 with a larger proportion of females ($\chi2$=203.10; p<0.001). The current study provide important information that can facilitate management, conservation, and sustainable fishing of *T. lepturus* in the Persain Gulf.

Keywords: Life history traits, Reproduction, *Trichurus lepturus*, Fisheries, Persian Gulf

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

Introduction

Many fish species in the Persian Gulf have been overfished over the past two decades, due to the increased fishing effort that exceeds the optimal level for most pelagic and demersal species (Shojaei *et al*., 2007; Taghavimotlagh and Shojaei, 2009; Grandcourt, 2012). In recent years fishermen on the northern coast of the Persian Gulf and Oman Sea repeatedly complain that the catch of fishes has declined, and thus the interest has been shifted toward the less harvested and non-exploited species (Taghavimotlagh *et al*., 2008; Hakimelahi *et al.,* 2010). Ribbonfish (*Trichiurus lepturus*) is one of the species that has been proposed as an interesting complement since early 2000s.

The ribbonfish is a bentho-pelagic species found worldwide in tropical and subtropical regions, mainly between 45^o S and 60^o N. (Randall, 1995). It occurs from shallow inshore waters to up to 300 m depth while aggregating in dense schools. The species switch between estuarine and marine ecosystems, according to its life cycle stage and food demand (Kwok and Ni, 1999; Elliott *et al*., 2007; Ghosh *et al*., 2009). *T. lepturus* feeds on a variety of pelagic and demersal fishes, and crustaceans, while may exhibit cannibalism toward small juvanials (Martins *et al*., 2005). Ribbonfish is a significant fish resource of the Iranian Exclusive Economic Zone (EEZ), contributing to about 5% and 13% of the biomass of the Persian Gulf and Oman Sea coasts (Taghavimotlagh and Shojaei, 2018). The fish is not consumed by local populations and not marketed in Iran. However, it is commercially important due to its high demand for export to China and other Asian countries. The average catch has increased from 10235 tones in 1997 to 55890 tons in 2019 (Fig. 1). Surprisingly, the catch rate of ribbonfish increased seven-fold in a decade (2010 – 2019) and now ranked third among the exploited marine fishery resources of Iran. Along the coast of the Persian Gulf, it is caught by the traditional fishing sector using hand-line and drift gillnet and by the commercial sector using midwater trawling. Currently, the boats are equipped with low power light-emitting diode panels (LEDs) that are designed to increase fish attraction to the baits. Currently, the strong fishing effort, has raised concerns of possible recruitment failure on Northern coast of the Persian Gulf and Oman Sea. Developing conservation efforts require information on the past and current status of the stock and the patterns that shape the species' biological cycles. On account of the current status of ribbonfish populations, conservation measures are required, and knowledge on the species’ growth and mortality rates as well as life history traits is a prerequisite for designing effective management strategies. Among the life history traits, reproduction represents significant aspects that the preservation of viable populations depending on its success (Jakobsen *et al*., 2016). Different aspects of growth and reproductive features such as infinity length, size at first maturity, sex ratio, type of spawning, and annual reproductive cycle are essential to assess the spawning stock and used to develop the standard guidelines (Armsworth, 2001; Taghavimotlagh *et al*., 2010; Taghavimotlagh *et al*., 2012). Several studies on the growth and reproductive biology of *T. lepturus* have been previously undertaken in some regions of the northern hemisphere, including Indian Ocean (Thiagarajan *et al*., 1992), the China seas (Kwok and Ni, 1999), the SW Atlantic (Martins and Haimovici, 2000), the Arabian Sea (Al-Nahdi *et al*., 2009) and the Persian Gulf (Raeisi *et al*., 2012; Taghavimotlagh and Shojaei, 2018). To our knowledge, no study has previously examined the life history traits of ribbonfish in the Northern coasts of the Persian Gulf and Oman Sea. To help fill information gaps, we collected biological samples from *T. lepturus* harvested in the Persian Gulf and Oman Sea to estimate their growth and mortality parameters and life-history traits including sex ratio, size at first maturation (L_{M50}), reproductive seasonality, and growth.

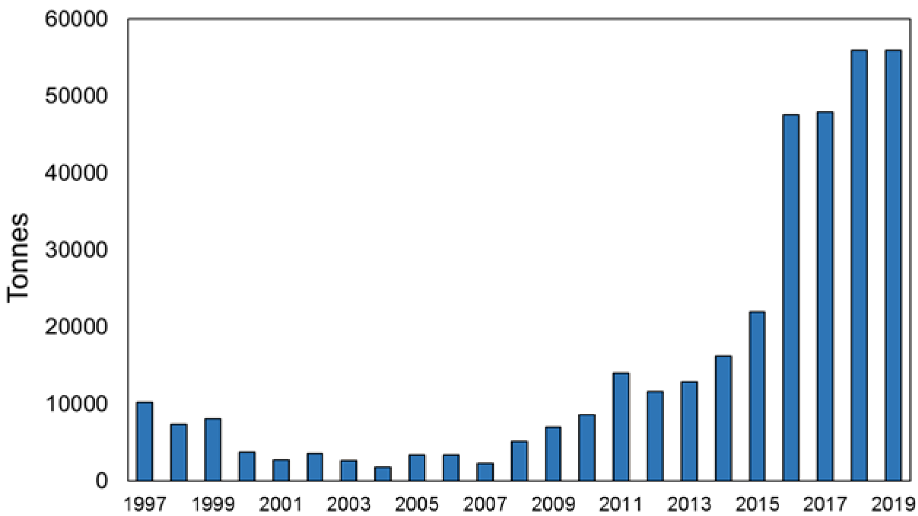

Figure 1: Trends of landings of *T. lepturus* caught in waters of Iran (Persian Gulf and Oman Sea) from 1997-2016.

Materials and methods

Sampling and measurements

T. lepturus were collected randomly from coastal waters off the Persian Gulf and Oman Sea, Iran, from March 2016 to February 2017 (Fig. 2). Fish were sampled using bottom trawls (stretched cod-end mesh size of 22 - 24 mm), gillnet, and hand line fishing gear. During sampling events, the total length (L_T, cm) and body mass (M_B, g), were recorded for the individuals to the nearest 0.1 cm and nearest 0.1 g, respectively. In total, 3321 individuals were collected randomly from a large pool of individuals to estimate the size distribution, growth parameters, and mortality rates. Additionally, a sub-sample of 30 to 35 individuals were monthly sampled and transported to the laboratory in ice for further analysis. All gonads (M_G) were weighted to the nearest 0.01 g with an AND scale (GF 3000; www.aandd.jp).

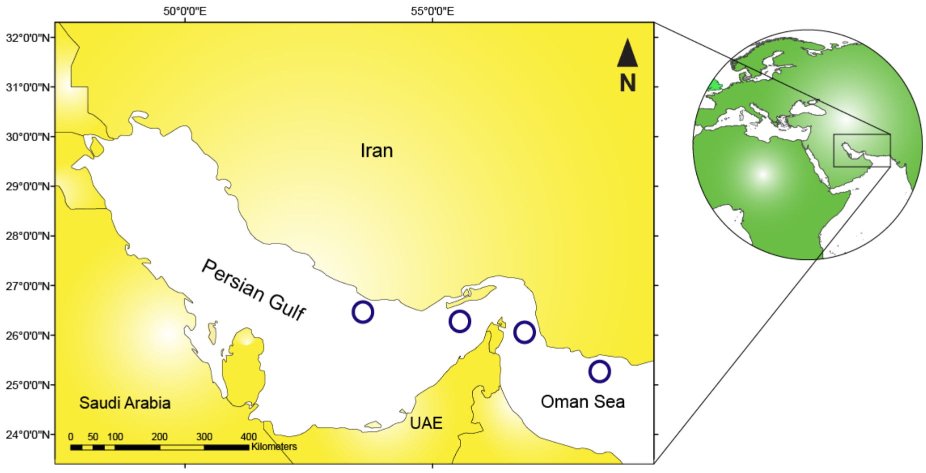

Figure 2: Sampling locations (shaded line) for *T. lepturus* in the Persian Gulf and Oman Sea, March 2016–February 2017.

Length-weight relationship

The relationship between length and body mass was calculated using: $M_B=aL_T^b$, where *a* is a scaling constant and *b* is the allometric growth parameter (Hayes *et al.*, 1995). The parameters *a* and *b* were estimated by the least-squares linear regression analysis based on natural logarithms: $\ln(M_B)=\ln(a)+\ln(L_T)$ Significant difference of *b* values from the isometric threshold, *i.e.*, 3, was tested by the t-test (Pauly, 1983). The difference in L_T - M_B relationship between sexes was examined by the maximum likelihood ratio test (Kimura, 1980).

Growth and mortality

The von Bertalanffy growth function (VBGF) was used to evaluate the infinitive length (L_∞) and growth coefficient (K) of the *T. lepturus* (Pauly, 1983). The VBGF is defined as:

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

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):

$$Log\,(-t0) = -0.3922 - 0.275 \log L_\infty - 1.0381 \log K$$

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

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

The total mortality (Z) is the sum of the natural mortality (M), and fishing mortality (F) was calculated using the length converted catch curve method (Pauly, 1983). Additionally, Pauly's empirical equation (Pauly, 1980) is 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* is 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 (Mace, 1994). The TropFishR package available in R software was used to estimate the growth and mortality rates from length-frequency data (R-Team, 2017).

Spawning pattern and length at maturity

The gonads of each fish were evaluated macroscopically for sex and stage of reproductive development based on the characteristics described by (Kwok and Ni, 1999). Six commonly identified stages were utilized as a threshold to discriminate fishes showing different gonadal stages (Table 1).

Table 1: Macroscopic criteria for assessing stages of reproductive development in female *Trichiurus lepturus*, adapted from Kwok and Ni, (Kwok and Ni, 1999).

Reproductive stage		Macroscopic characteristic
I	Immature	Ovaries glassy, narrow and short, eggs invisible.
II	Developing	Ovary opaque, eggs distinguishable. Ovary about 50% length of ventral cavity
III	Spawning capable	Ovary yellow to orange, opaque oocytes visible through epithelium. Ovary about 60-70% length of ventral cavity
IV	Actively Spawning	Ovary well rounded, filled, hydrated eggs large and visible through epithelium, can easily be counted. Eggs transparent, can be released when pressed. Ovary about 80% length of ventral cavity. well rounded.
V	Regressing	Ovary translucid with garnet color
VI	Regenerating	Ovary shrunk and flaccid

All ovaries at stages 4 or higher were considered mature. The gonado-somatic index (GSI), was calculated by the equation $GSI(\%)=(MG/MB)*100$. The sex ratio was taken across all samples for which sex could be determined and tested using $\chi 2$-test to know if the sex ratio differed significantly from a 1:1. Differences between the mean size of females and males were tested with a two-sample independent t-test. Size at sexual maturity (L_{M50}) is defined as the size at which 50% of the fish has reached maturity and is ready to spawn (King, 2013). The proportion $(P_i=M_i/J_i)$, of mature individuals by size class (i) was calculated in 1 cm intervals, where

(M_i)= number of mature specimens in size class *i*; J_i= total number of individuals examined from the same size class *i* (immatures and matures). To estimate size at first sexual maturity (L_{M50}), the data were fitted to a logistical function. We used the logistic curve equation (King, 2013): $P=1/1+e^{-r(L_T-LM_{50})}$, where P=proportion of mature individuals; L_T=total length corresponding to the proportion (P); r=slope of curve; L_{M50}=total length at 50% mature. All specimens assigned to III or higher stages of maturity were judged mature. All statistical analyses were conducted using Microsoft Excel 2013 and R 3.4.3 (R-Team, 2017). The raw data on growth and life history traits of *T. lepturus* is available at PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.917549.

Results

Length-weight relationship

All of the samples were phenotypically identified to species level immediately in the field following Fischer and Bianchi (1984). Females ranging in size from 50.5 to 114.5 cm L_T with a body mass of 129.3 - 937.1 g, whereas males were in the range of 53.5 - 86 cm L_T, with body mass between 114.6 and 592.5 g. Females were on average (81.55±8.95 cm L_T) larger than males (69.03±8.55 cm L_T) and this difference was statistically significant (t=1.96, p<0.01). From these data, mass–length relationships were generated and described by: $M_B=0.0001\ L_T^{3.47}$ (R^2=0.91; N=262, p<0.001) for females (Fig. 3a) and $M_B=0.0004\ L_T^{3.15}$ (R^2=0.87; N=43, p<0.001) for males (Fig. 3b). The differences of slopes of the length–mass regressions for males and females were significantly different (ANOVA, p<0.01).

Growth and mortality

The results of the response surface analysis provided the best fit of growth model *i.e.*, L_∞=121.5 cm and K=0.29. These parameters were later used in all the calculations. The values of t_0 and φ' were estimated as –0.32 year, and 3.63 respectively. The natural mortality (M) estimated by Pauly's method presented a rate of 0.53 yr^{-1}. The annual rate of total mortality (Z) derived from catch curve analysis was 1.16 $year^{-1}$. 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 0.5 $year^{-1}$ and 0.37 $year^{-1}$, respectively.

Spawning period and length at maturity (L_{M50})

Sex, gonad mass, and reproductive state were evaluated from a sub-sample of 380 *T. lepturus*. Females outnumbered males throughout the year with the sex ratio of 321:59, which was significantly different from 1:1 (X^2, p<0.01). Males were absent from August to October and, 74% of males have recorded from February to June, which correspond to the reproductive period of *T. lepturus*.

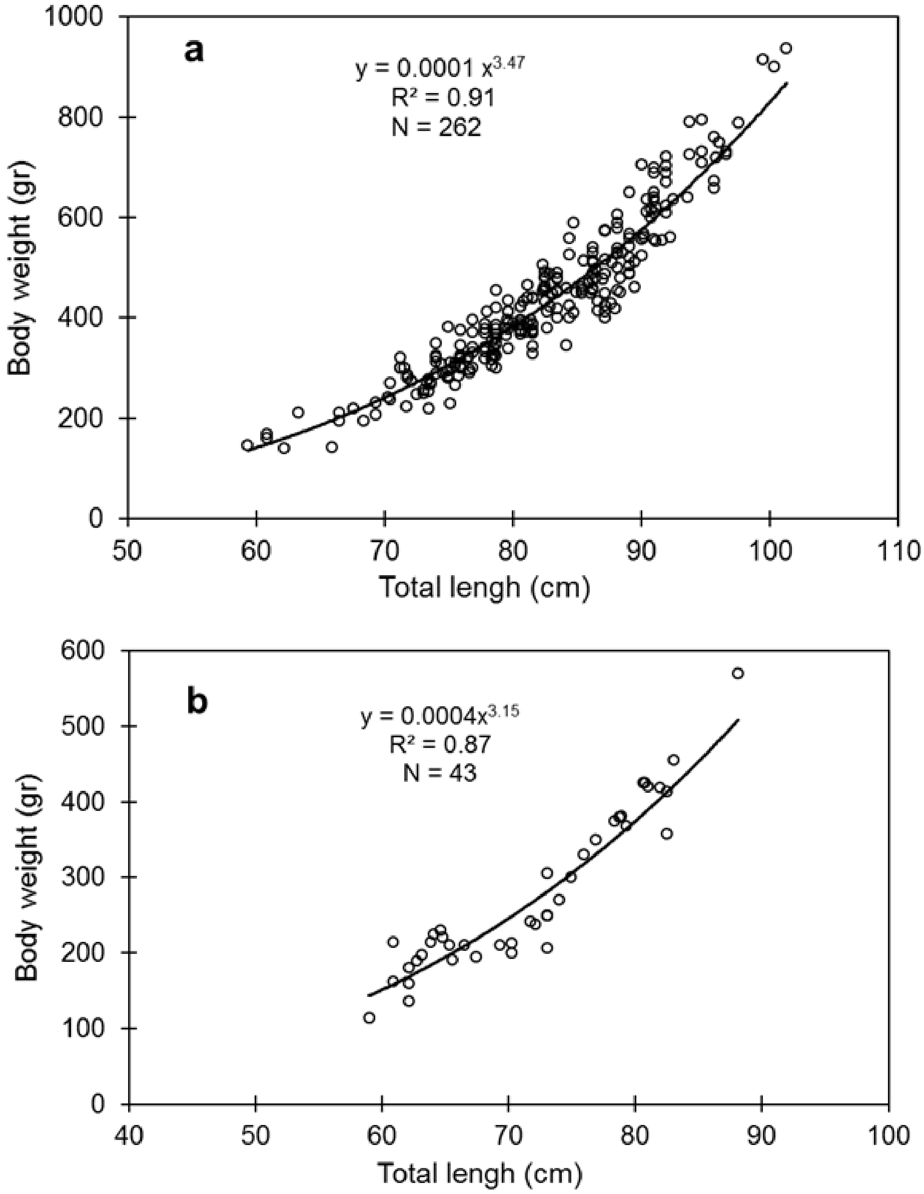

Figure 3: Relationships between total length and body weight of *T. lepturus* for (a) female and (b) male in the coastal waters of Persian Gulf and Oman Sea.

The mean GSI of females increased from 1.72 in February to a peak of 4.98 in March, decreased thereafter to the lowest value at 0.76 in September, and then gradually increased (Fig. 4). The macroscopic appearance of ovary maturity indicated that most of the immature ovaries were present from July to October, with mature ovaries appearing throughout the sampling year (Fig. 5). The smallest mature female was 66.2 cm LT. The size at first maturity of the ribbonfish females was attained at 70.9 cm LT (Fig. 6).

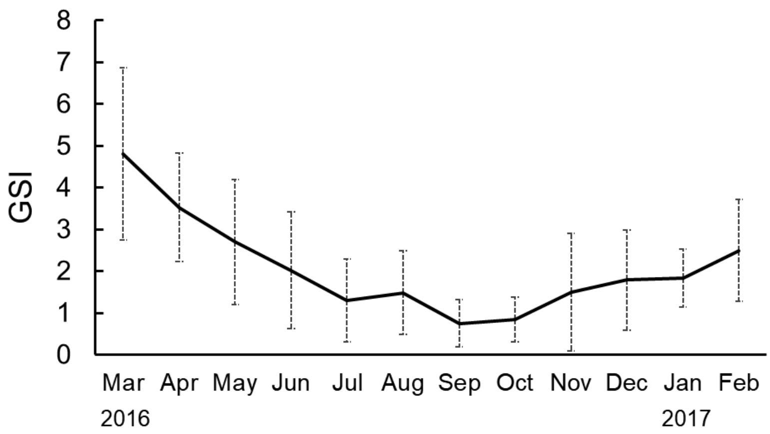

Figure 4: Monthly changes in gonadosomatic index (GSI) for *T. lepturus*, Persian Gulf and Oman Sea, March 2016 to February 2017

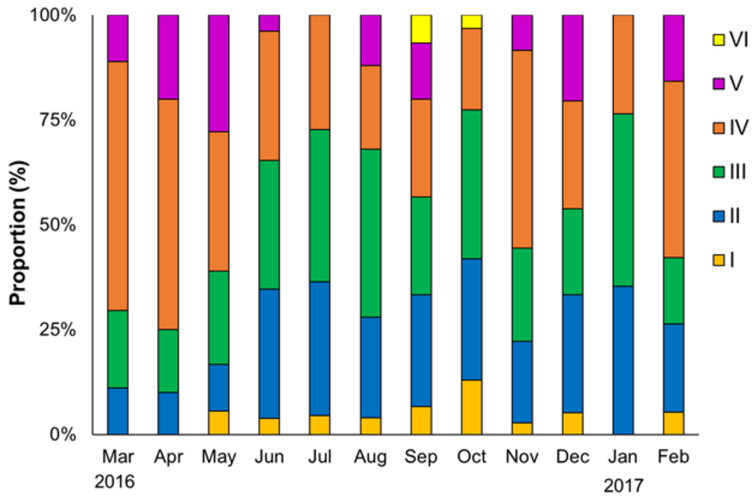

Figure 5: Monthly changes in proportion of ovary maturity stage, *Trichiurus lepturus* females (n = 300), Persian Gulf and Oman Sea (March 2016 to February 2017).

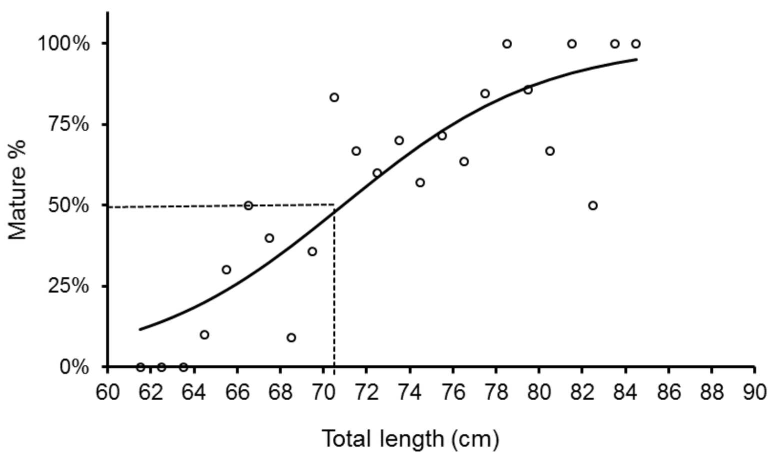

Figure 6: Size at 50% sexual maturity, *T. lepturus* females, the Persian Gulf and Oman Sea (March 2016 to February 2017). Data points = observed values; line = fitted values.

Discussion

The length-mass relationship showed that *T. lepturus* exhibited positive allometric growth. It agrees well with the results of studies reported from the Arabian Sea and the Indian Ocean (Reuben *et al*., 1997; Al-Nahdi *et al*., 2009; Ghosh *et al*., 2014). The small variations could be related to different biological factors such as food quality, habitat, spawning season, and a length range of sampled specimens (Balon, 1985). The ribbonfish exhibit asymptotic growth ranging from 106.82 cm L_T (Ruben *et al*, 1997) to 152.4 cm L_T (Liang and Pauly, 2017), with different growth rates ranging from 0.13 yr^{-1} (Avinash *et al*., 2014) and 0.72 yr^{-1} (Abdussamad *et al*., 2006). Growth parameters are essential parameters to estimate the stock size, recruitment, and mortality of the fish population (King, 2013). The growth parameters varied within the stocks that might experience different environmental conditions. Food availability and water temperature might influence the growth of fish and further affect the population's mean size (Yoneda and Wright, 2005). The growth parameters obtained for the present study revealed a lower L_∞ value compared to the values calculated in the Indian Ocean. . The field observations indicate that the fish mean length 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 0.29 per year that is nearly comparable with the research done by Ghosh *et al*. (2009), but lower than that estimate (0.72) by Abdussamad *et al*. (2006). The value of performance index (3.63) in the present study was comparable with many previously published reports by similar studies in FAO 51 region (Ghosh *et al*., 2009; Avinash *et al*., 2014; Taghavimotlagh and Shojaei, 2018). In the Indian Ocean, values of φ' range from 3.35 to 4.1 (Abdussamad *et al*., 2006; Avinash *et al*., 2014). One possible explanation for such differences may be related to the fact that ribbonfish undergoes different stanzas of growth rates (Liang and Pauly, 2017). In the current study, the total mortality (Z), natural mortality (M) and fishing mortality (F) were estimated 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 (Abdussamad *et al*., 2006). The values of exploitation rate (E), target and limit reference points confirm that the ribbonfish stock is under high fishing pressure. Higher demand for ribbonfish in recent years, together with operating improved mid-water trawl nets that catches>70% of ribbonfish, has resulted in higher catches that may lead to overexploitation. Ribbonfish trawlers conduct fishing voyages for 7-15 days beyond the EEZ (Shojaei and Taghavimotlagh, 2011). Along with commercial vessels, traditional fishing sectors are targeting ribbonfish using boats equipped with LEDs. Available information indicates that traditional fishermen may contribute as much as 50% of the country's total ribbonfish catch.

In the current study, we found substantial differences in size between females and males with 18 cm difference in their maximum size. These differences are attributed to natural sexual dimorphism, when a large body size confers an adaptive advantage for females, possibly because large females are more fecund and lay larger eggs than small females, increasing reproductive success (Wootton, 1992; Filous *et al*., 2019). The sex ratio of the ribbonfish population skewed towards females, which is also observed in South China coasts and Mexico (Kwok and Ni, 1999; De la Cruz-Torres *et al*., 2014). Several factors may influence the sexes differently, including growth, mortality, and behavior (King, 2013). The observed minimum size of sexual maturation was 60.1 cm L_T for females based on the macroscopic analysis of the gonads. The size at maturity varied considerably within the specimens that might experience different environmental conditions (Froese and Binohlan, 2000). The estimated size at first maturity for females was 70.9 cm LT based on all sampled from the year-round sampling. Various authors reported different size at first maturity f or *T. lepturus* in different water bodies of the world. Martins and Haimovici (2000) estimated the size at maturity of *T. lepturus* to be 69.3 cm L_T in southern Brazil. From work done on a fish community on the northwest coast of India, Khan (2006) noted that the size at maturity is 75 cm L_T. Al-Nahdi *et al*. (2009) showed that maturity is reached at 79 L_T in the Arabian Sea. The small range of sizes at maturity attribute d to variability in growth rates and lifespan and suggests the adaptability of the ribbonfish to different environments (Martins and Haimovici, 2000). Food availability, stock density, and water temperature might influence the growth of fish and further affect their gonadal development and size at first maturity (Yoneda and Wright, 2005). Generally, higher estimates of size at Maturity for *T. lepturus* correspond to the regions where marked temprature cycles and lower annual mean temperature occur. The Persian Gulf is categorized as subtropical and usually does not undergo marked temperature cycles (Sheppard *et al*., 2010). Additionally, 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. As the L_{M50} is useful for overfished species management, this information can be used to define the optimal mesh size for conservation measures to avoid overfishing and achieve sustainable fisheries.

Several authors have reported the high flexibility in the reproductive strategy of the *T. lepturus* at low latitudes and warm regions (e.g., Al-Nahdi *et al*., 2009). Our results indicate that *T. lepturus* exhibits an asynchronous ovary development characterized by the presence of oocytes at different stages of development at the same time. The occurrence of mature female, together with GSI data indicates that *T. lepturus* exhibit a prolonged spawning season throughout the year. These findings are consistent with that reported by Khan (2006) showed that *T. lepturus*, off the northwest coast of India, individual fish spawn once in a year but had an extended spawning season (October to May). A year-round spawning cycle indicates that the populations spawn twice a year or are composed of two broodstocks (Al-Nahdi *et al*., 2009; Fakoya and Anetekha, 2019). Additionally, in warmer and less productive environments, smaller batch fecundity, due to smaller size may partly be compensated by longer spawning seasons (Martins and Haimovici, 2000). A prolonged spawning season has also been reported for many other species in temperate waters (Wieland *et al*., 2000). This reproductive strategy has been suggested as reducing the negative impacts of environmental variation on reproductive success (Bobko and Berkeley, 2004).

In conclusion, the results of the current study provide fundamental information on the growth, mortality and reproductive biology of *T. lepturus*, which are prerequisites for effective management of this commercially valuable fishery resource in the Persian Gulf. A detailed study of the reproductive cycle represents the time of the year when the stocks become more vulnerable to fishery's impacts. Given the protracted spawning season, partial closure of the fishery for a portion of the annual spawning season would further increase the abundance of breeding stock, reduce fishing mortality and ensure the long-term sustainability of the fishery. From the results presented in this study, it is possible 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 further monitored and linked to a stock assessment of the species, to facilitate future interpretation of the impact of increased catch levels on population dynamics and fishery-resource status of the stocks.

Acknowledgments

We are deeply indebted to all the persons who contributed to sampling, sample sorting, and taxonomic identification. We also thank the crew of “Kish” vessels for their help with sampling. This work has been supported by the Iranian National Science Foundation (I NSF) (grant no. 930424000) and Iranian Fisheries Science Research Institute.

References

Abdussamad, E.M., Nair, P.N. and Achayya, P., 2006. The ribbonfish fishery and stock assessment of *Trichiurus lepturus* Linnaeus off Kakinada, east coast of India.

Journal of the Marine Biological Association of India, 48(**1**), 41–45.

Al-Nahdi, A., Al-Marzouqi, A., Al-Rasadi, E. and Groeneveld, J.C., 2009. The size composition, reproductive biology, age and growth of largehead cutlassfish *Trichiurus lepturus* Linnaeus from the Arabian Sea coast of Oman. *Indian Journal of Fisheries*, 56(**2**), 73–79.

Armsworth, P.R., 2001. Effects of fishing on a protogynous hermaphrodite. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(**3**), 568–578. DOI:10.1139/f01-015

Avinash, R., Desai, A.Y. and Ghosh, S., 2014. Population dynamics of *Trichiurus lepturus* (Linnaeus, 1758) off Veraval. *Indian Journal of Fisheries*, 61(**2**), 14–18.

Balon, E.K., 1985. Early life histories of fishes: new developmental, ecological and evolutionary perspectives (Issue 597.03 BALe).

Bobko, S.J., and Berkeley, S.A., 2004. Maturity, ovarian cycle, fecundity, and age-specific parturition of black rockfish (*Sebastes melanops*). *Fishery Bulletin*, 102(**3**), 418–429.

De la Cruz-Torres, J., Martínez-Pérez, J.A., Franco-López, J. and Ramírez-Villalobos, A.J., 2014. Biological and Ecological Aspects of *Trichiurus lepturus* Linnaeus, 1758 (Perciformes: Trichiuridae) in Boca Del Rio, Veracruz, Mexico. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 14(**10**), 1058–1066.

Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G. and Harrison, T.D., 2007. The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and Fisheries*, 8(**3**), 241–268. DOI:10.1111/j.1467-2679.2007.00253.x

Fakoya, K.A. and Anetekha, M.A., 2019. Macroscopic gonad staging and reproductive seasonality in the Gorean snapper, *Lutjanus goreensis* a gonochoristic West African Lutjanid. *West African Journal of Applied Ecology*, 27(**1**), 1–22.

Filous, A., Lennox, R.J., Coleman, R.R., Friedlander, A.M., Clua, E.E.G. and Danylchuk, A.J., 2019. Life history characteristics of an exploited bonefish *Albula glossodonta* population in a remote South Pacific Atoll. *Journal of Fish Biology*, 95(**2**), 562–574. DOI:10.1111/jfb.14057

Fischer, W. and Bianchi, G., 1984. FAO species identification sheets for fishery purposes: Western Indian Ocean (Fishing Area 51). v. 1: Introductory material. Bony fishes, families: Acanthuridae to Clupeidae.-v. 2: Bony fishes, families: Congiopodidae to Lophotidae.-v. 3: families: Lut.

Froese, R. and Binohlan, C., 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *Journal of Fish*

Biology, 56(**4**), 758–773.

Ghosh, S., Pillai, N.G.K. and Dhokia, H.K., 2009. Fishery and population dynamics of *Trichiurus lepturus* (Linnaeus) off Veraval, north-west coast of India. *Indian Journal of Fisheries*, 56(**4**), 241–247.

Ghosh, S., Rao, M.V., Rohit, P., Rammohan, K. and Maheswarudu, G., 2014. Reproductive biology, trophodynamics and stock structure of ribbonfish *Trichiurus lepturus* from northern Arabian Sea and northern Bay of Bengal. *Indian Journal of Geo-Marine Sciences*, 43(**5**), 755–771.

Grandcourt, E., 2012. Reef fish and fisheries in the Gulf. In Coral Reefs of the Gulf (pp. 127–161). Springer.

Hakimelahi, M., Kamrani, E., Taghavimotlagh, S.A., Shojaei. M.G. and Vahabnezhad, A., 2010. Growth parameters and mortality rates of Liza klunzingeri in the Iranian waters of the Persian Gulf and Oman Sea, using Length Frequency Data. *Iranina Journal of Fisheries Science*, 9(**1**), 87-86. DOI:10.22092/IJFS.2018.120058.

Hayes, D.B., Brodziak, J.K.T. and O'Gorman, J.B., 1995. Efficiency and bias of estimators and sampling designs for determining length-weight relationships of fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 52(**1**), 84–92. DOI:10.1139/f95-008

Jakobsen, T., Megrey, B.A. and Moksness, E., 2016. Fish reproductive biology: implications for assessment and management. John Wiley and Sons.

Khan, M.Z., 2006. Fishery resource characteristics and stock assessment of ribbonfish, *Trichiurus lepturus* (Linnaeus). *Indian Journal of Fisheries*, 53(**1**), 1–12.

Kimura, D.K., 1980. Likelihood methods for the von Bertalanffy growth curve. *Fishery Bulletin*, 77(**4**), 765–776.

King, M., 2013. Fisheries biology, assessment and management. John Wiley and Sons.

Kwok, K.Y. and Ni, I.H., 1999. Reproduction of cutlassfishes *Trichiurus* spp. from the South China Sea. *Marine Ecology Progress Series*, 176, 39–47. DOI:10.3354/meps176039

Liang, C. and Pauly, D., 2017. Growth and mortality of exploited fishes in China's coastal seas and their uses for yield per recruit analyses. *Journal of Applied Ichthyology*, 33(**4**), 746–756. DOI:10.1111/jai.13379

Mace, P.M., 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Canadian Journal of Fisheries and Aquatic Sciences*, 51(**1**), 110–122. DOI:10.1139/f94-013

Martins, A.S. and Haimovici, M., 2000. Reproduction of the cutlassfish *Trichiurus lepturus* in the southern Brazil subtropical convergence ecosystem. *Scientia Marina*, 64(**1**), 97-105.

DOI:10.3989/scimar.2000.64n197

Martins, A.S. , Haimovici, M. and Palacios, R., 2005. Diet and feeding of the cutlassfish *Trichiurus lepturus* in the subtropical convergence ecosystem of southern Brazil. *Journal of the Marine Biological Association of the United Kingdom*, 85(**5**), 1223–1229. 10.12691/aees-8-2-1

Pauly, D., 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science*, 39(**2**), 175–192.

Pauly, D. and Munro, J.L., 1984. Once more on the comparison of growth in fish and invertebrates. *Fishbyte*, 2(**1**), 1–21.

Pauly, D., 1983. Some simple methods for the assessment of tropical fish stocks (Issue 234). *Food and Agriculture Organization*, 234, 52.

Raeisi, H., Hosseini, S.A. and Paighambari, S.Y., 2012. Abundance of Cutlassfish *Trichiurus lepturus* (Linnaeus, 1758) in Bushehr Waters, Persian Gulf. *Annual* Research and Review in Biology. pp. 37–45.

Randall, J.E., 1995. Coastal fishes of Oman. University of Hawaii Press. 439 P.

Reuben, S., Vijayakumaran, K., Achayya, P. and Prabhakar, R.V.D., 1997. Biology and exploitation of *Trichiurus lepturus* Linnaeus from Visakhapatnam waters. *Indian Journal of Fisheries*, 44(**2**), 101–110.

Sale, P.F., Feary, D.A., Burt, J.A., Bauman, A.G., Cavalcante, G.H., Drouillard, K.G., Kjerfve, B., Marquis, E., Trick, C.G. and Usseglio, P., 2011. The growing need for sustainable ecological management of marine communities of the Persian Gulf. *Ambio*, 40(**1**), 4–17. DOI: 10.1007/s13280-010-0092-6

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., Benzoni, F., Dutrieux, E., Dulvy, N.K. and Durvasula, S.R.V., 2010. The Gulf: a young sea in decline. *Marine Pollution Bulletin*, 60(**1**), 13–38. DOI:10.1016/j.marpolbul.2009.10.017

Shojaei, M.G. and Taghavimotlagh, S.A., 2011. The catch per unit of swept area (CPUA) and estimated biomass of large head hairtail (*Trichiurus lepturus*) with an improved trawl in the Persian gulf and gulf of Oman, Iran. *Asian Fisheries Science*, 24(**2**), 209–217.

Shojaei, M.G., Taghavimotlagh, S.A., Seyfabadi, J., Abtahi, B. and Dehghani, R., 2007. Age, growth and mortality rate of the narrow-barred Spanish Mackerel (*Scomberomerus commerson* Lacepede, 1800) in coastal waters of Iran from length frequency data. *Turkish Journal of Fisheries and Aquatic Sciences*, 7(**2**), 115–121.

Taghavimotlagh, S.A., Seyfabadi, S.J., Shojaei, M.G., Abtahi, B. and Taheri Mirghaed, A., 2008. Population dynamics of the Spanish mackerel (*Scomberomorus commerson*) in coastal waters of Oman Sea. *Iranian Journal of Fisheries Sciences*, 7(**2**), 257-270.

Taghavi Motlagh, S.A. and Shojaei, M.G., 2009. Population dynamics of narrow-barred Spanish mackerel (*Scomberomorus commerson*) in the Persian Gulf, Bushehr province, Iran. *Indian Journal of Fisheries*, 56(**1**), 7–11.

Taghavimotlagh, S.A., Vahabnezhad, A., Seyfabadi, S.J., Shojaei, M.G. and Hakimelahi, M., 2010. Growth, mortality and spawning season of the spangled emperor (*Lethrinus nebulosus* Forsskal, 1775) in coastal waters of Hormozgan Province in the Persian Gulf and Oman Sea. *Iranian Journal of Fisheries Sciences*, 9(**1**), 161-172.

Taghavimotlagh, S.A., Hakimelahi, Shojaei, M.G., Vahabnezhad, A. and Taheri Mirghaed, A. 2012. Feeding habits and stomach contents of Silver Sillago, *Sillago sihama*, in the northern Persian Gulf. *Iranian Scientific Fisheries Journal*, 11(**4**), 892-901.
DOI:10.22092/IJFS.2018.114251

Taghavimotlagh, S.A., and Shojaei, M.G., 2018. Fishery management based on relative yield-per-recruit model for the Largehead Hairtail (*Trichiurus lepturus*) stocks in the Persian Gulf and Oman Sea. *Iranian Scientific Fisheries Journal*, 26(**6**), 93–102.
DOI:10.22092/ISFJ.2018.115763

The R Core Team,. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Thiagarajan, R., Lazarus, S., Appanasastry, Y., Khan, M.Z., Mohamad Kasim, H. and Scariah, K.S., 1992. Stock assessment of the ribbonfish, *Trichiurus lepturus* Linnaeus, from the Indian waters. *Indian Journal of Fisheries*, 39(**3-4**), 182–194. DOI: 10.3923/jfas.2011.212.224

Wieland, K., Jarre-Teichmann, A. and Horbowa, K., 2000. Changes in the timing of spawning of Baltic cod: possible causes and implications for recruitment. *ICES Journal of Marine Science*, 57(**2**), 452–464.

Wootton, R.J., 1992. Constraints in the evolution of fish life histories. *Netherlands Journal of Zoology*, 42(**2**), 291–303.

Yoneda, M. and Wright, P.J., 2005. Effects of varying temperature and food availability on growth and reproduction in first time spawning female Atlantic cod. *Journal of Fish Biology*, 67(**5**), 1225–1241. DO10.1111/j.1095-8649.2005.00819.x