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Eugenia Amador

Department of Fisheries and
Aquatic Sciences, University of
Cape Coast, Cape Coast, Ghana

Joseph Aggrey-Fynn

Department of Fisheries and
Aquatic Sciences, University of
Cape Coast, Cape Coast, Ghana

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Growth, mortality, sexual maturity and exploitation of the ribbonfish, *Trichiurus lepturus* (Linnaeus, 1758) (Pisces: Trichiuridae) in Ghanaian waters

Eugenia Amador and Joseph Aggrey-Fynn

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Abstract

The ribbonfish, *Trichiurus lepturus* is actively and locally exploited by commercial fishers along the coast of Ghana. As a contribution to fill the knowledge gap on this species, size composition, growth and mortality as well as sexual maturity and exploitation of the stocks were assessed. Samples were collected from major fish landing sites along the coast of Ghana from September, 2018 and August, 2019. Length-frequency data were used in the estimation of growth and mortality rates and exploitation ratio. Total lengths of *T. lepturus* sampled ranged between 24.8 and 103.9 cm with a unimodal distribution of 55 cm. The length and weight relationship established that growth was positively allometric. The asymptotic length (L_{∞}), growth coefficient (K) and age at zero length (t_0) for *T. lepturus* were estimated as 133.66, 0.46 yr⁻¹ and -0.88 respectively. Total (Z), fishing (F) and natural (M) mortality rates of were estimated at 2.69 yr⁻¹, 2.03 yr⁻¹ and 0.66 yr⁻¹ respectively. The length at first capture (L_c) was lower than the length at first maturity (L_m). Spawning occurred all year round with a peak spawning period from March to June. Fecundity was estimated to be 17,440 ± 1,250 eggs (mean ± SE). There was no significant difference observed in the sex ratio between males and females. The species showed to be vulnerable to overfishing. There is therefore the need for a reduction in fishing pressure of the stocks to promote proper management of this fishery resource.

Keywords: *Trichiurus lepturus*, length-frequency distribution, growth and mortality parameters, gonadosomatic index, fecundity

1. Introduction

The ribbonfish, *Trichiurus lepturus*, (Linnaeus, 1758), also known as largehead hairtail, is a benthopelagic fish of commercial importance worldwide. The ribbonfish is a cosmopolitan fish normally found in warm and warm-temperate shelf waters ^[1]. Although considered a worldwide species by several authors, *T. lepturus* is now known with certainty only from the western Atlantic and Indo-west Pacific regions ^[2]. This species can move between estuarine and marine ecosystems, including inshore and deep-sea areas, depending on its life-cycle stages and demand for food. They are distributed between the shallow and inshore waters to about 350 m depth in the offshore waters and mostly occur in dense schools along continental shores in tropical to temperate waters ^[3]. In Ghana, the species occurs in the coastal waters and are mostly caught with bottom trawls and beach seines ^[4]. During the survey of the pelagic and demersal resources of the Western Gulf of Guinea by "R/V Dr. Fridtjof Nansen" ribbonfishes were found in relatively high catch rates in the outer shelf (51-100 m) of Ghanaian waters ^[5].

The ribbonfish stands out among the highly exploited fishes and exported fishes worldwide. In Ghana, it contributed up to 8.78% and 10.26% of the total demersal landings in 2007 and 2015 and 2.46% and 2.28% among landings of both pelagic and demersal resources combined, respectively ^[6]. The Fridtjof Nansen survey of the pelagic and demersal resources in Ghanaian waters report in 2019 indicate that ribbonfish dominated the inner shelf (0-50 m) with a mean catch rate of 174.3 kg/h representing 18.84% ^[7]. This species plays a key role in the marine resources of Ghana and supports livelihood of fishers, thus contributes significantly to food and nutritional security. Due to the significant contributions of *T. lepturus* to fisheries, a number of studies have been conducted in neighbouring and other international waters to inform the basis of sustainable management of this fishery resource. Numerous studies on stock assessment, fishery and population dynamics of the fish have been carried out in Indian waters ^[8, 9, 10, 11] and in Taiwan ^[12]; also reproductive studies in India ^[13] and in the

Corresponding Author:

Eugenia Amador

Department of Fisheries and
Aquatic Sciences, University of
Cape Coast, Cape Coast, Ghana

Philippines^[14], biological and ecological aspects in Mexico^[15], morphometric variation in Kenyan waters^[16], age structure in China^[17] and diet and feeding behavior of the ribbonfish in Nigeria^[18].

However, in Ghana the stocks of the fishery had not been assessed due to lack of information on the biology of the species.

To successfully manage this fishery resource, there is the need to know the biological characteristics of the fishery. It is against this backdrop that this study sought to assess the status of the *Trichiurus lepturus* in Ghanaian waters through the study of variables related to its population and reproductive characteristics, such as growth and mortality parameters, gonadosomatic index, fecundity and exploitation level with a view of obtaining information that would be useful in the

management of the fishery.

2. Materials and methods

2.1 Study area

The study was conducted along the coast of Ghana at three fish landing sites (Fig. 1). These sites were Tema Fishing Harbour in the Greater Accra Region (5°38'39.43"N, 0°0'58.55"E), Elmina fish quay in the Central Region (05°4'57.14"N, 1°21'2.29"W) and Albert Bosomtwi-Sam Fishing Harbour in the Western Region (4°56'28.91"N, 1°42'29.35"W). In addition, these sites represent the major fish markets where artisanal catches of *T. lepturus* are landed along the coastline of Ghana. Bottom trawls and beach seines are the main gears used in the exploitation of *T. lepturus* by the local fishers.

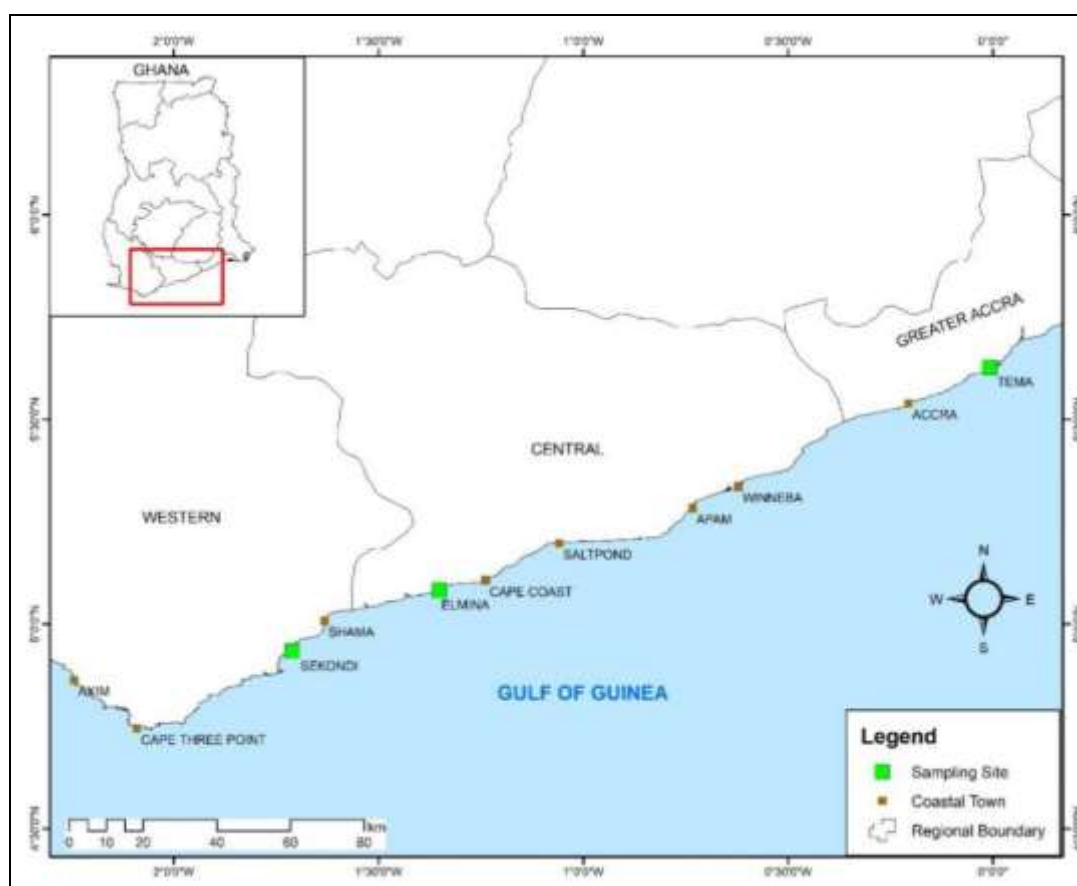


Fig 1: Fish sampling locations along the coast of Ghana

Fish samples were collected monthly from landings of artisanal fishermen from September 2018 to June 2019 at the 3 landing sites except in May, 2019 due to an observed closed season. Samples collected were put on ice and carried to the laboratory for sorting and identification. In July and August 2019, samples were collected onboard the Research Vessel, Dr. Fridtjof Nansen from bottom trawls. Stratified random sampling were carried out along the entire coast of Ghana. Length measurements including total length (TL) and pre-anal length (PAL) of each specimen were measured to the nearest 0.1 cm using a fish measuring board. Body weight (BW) of each specimen was also taken using Ohaus balance (Model: Ranger 7000) to the nearest 0.01g.

The length-weight relationship of *T. lepturus* was determined using the equation: $W = aTL^b$, where W is the total body weight (g) and TL is the fish total length (cm), a is the intercept of the regression and b is the growth coefficient^[19].

The b value from the length-weight equation was tested using the Student's t -test statistical analysis to ascertain the growth pattern of the population. The sex of each specimen was determined macroscopically by examining the gonads. The gonads were weighed to the nearest 0.01g and graded on a scale adopted by Holden & Raitt^[20] as follows: I- Immature, II- Maturing virgin and recovering spent, III- Ripening, IV- Ripe, V- Spent. Gonadosomatic index (GSI) was determined for males and females to assist in determination of spawning period. Fecundity for the various specimens was calculated using the formula by Bagenal, (1978)^[21]: $F = nG/g$; where F = fecundity, n = number of eggs in the subsample, G = total weight of the ovaries, g = weight of the subsample in the same units.

The monthly length data collected was analyzed using the R package TropFishR^[22] to assess the growth and mortality parameters following the steps outlined in the vignette on

TropFishR ELEFAN functions. TropFishR has traditional and updated versions of the Electronic Length Frequency Analysis (ELEFAN) method [23], used in growth parameter estimation, with new optimization techniques [22] and a complete set of methods for fisheries analysis with Length Frequency data. Growth rate (K), asymptotic length (L_{∞}) and the growth performance index (ϕ') of the species was estimated using the VBGF. The length-converted catch curve derived was used to estimate the total mortality rate (Z). Natural mortality rate (M) was calculated using the empirical formula:

$$\log(M) = -0.0066 - 0.279 \log(L_{\infty}) + 0.6543 \log K + 0.4634 \log(T)$$

where M = natural mortality, L_{∞} is the asymptotic

length of the fish and K refers to the growth coefficient [24]. The annual mean temperature, T, at sea was (26 °C) [7]. The exploitation ratio (E) was calculated by the quotient between fishing (F) and total mortality: $E = F/Z$ [25].

3. Results

Trawl stations along the coast of Ghana where populations of *T. lepturus* were captured during the Fridtjof Nansen survey are shown in Fig. 2. Denser populations with higher numbers of *T. lepturus* were observed in the western and central part of the coast as compared to a sparse distribution in the eastern coast.

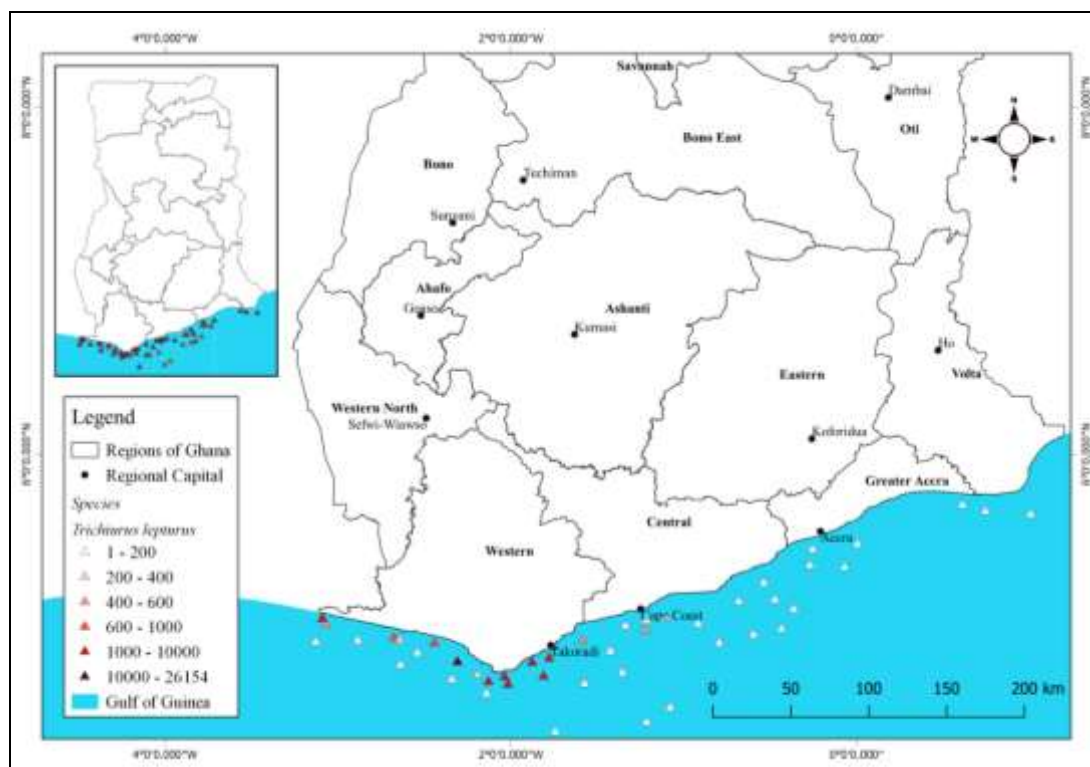


Fig 2: Distribution of *T. lepturus* along the coast of Ghana during RV Fridtjof Nansen survey in July and August 2019

A total of 1,677 specimens of *T. lepturus* were obtained during the study period. Total length ranged from 24.8 to 103.9 cm with a mean length of 57.2 ± 0.28 cm. The length-

frequency distribution showed a modal length class of 50.0 – 59.9 cm indicating a unimodal distribution of *T. lepturus* (Fig. 3).

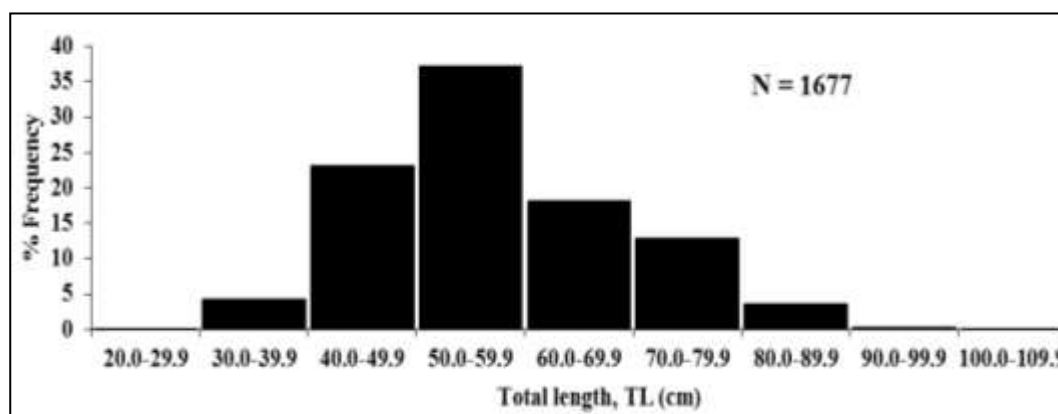


Fig 3: Length-frequency distribution of *T. lepturus* along the coast of Ghana

The length-weight relationship of the *T. lepturus* population was described by the equation: $BW = 0.0002TL^{3.3437}$ ($r = 0.98$), where BW = body weight in grams and TL = total

length in centimetres (Fig.4). The growth coefficient, $b = 3.3437$ was significantly different (student's t-test = 192.072; $p < 0.05$) from the hypothetical value 3 indicating positive

allometric growth. Nonetheless, the regression coefficient ($r=0.98$) of the equation indicated there was a strong positive correlation between weight and length of the *T. lepturus* population.

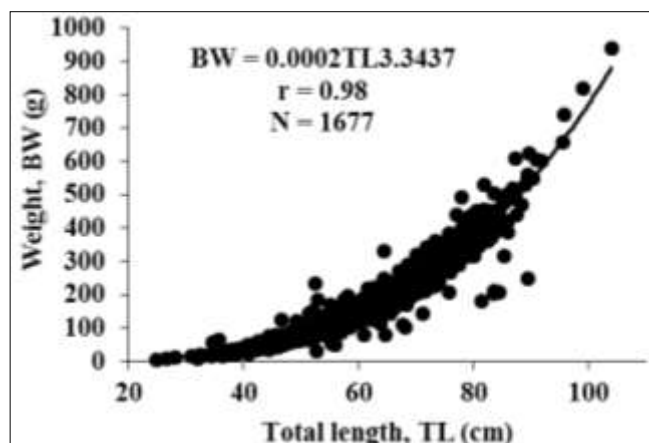


Fig 4: Length-weight relationship of *T. lepturus* along the coast of Ghana

The estimates of growth parameters of *T. lepturus* with 95% confidence interval is shown in Table 1.

Table 1: Growth and mortality parameters of *T. lepturus* along the coast of Ghana (September 2018 – August 2019)

Growth and Mortality parameters	<i>Trichiurus lepturus</i>
Asymptotic length (L_{∞})	133.66 cm
Maximum observed length (L_{max})	103.9cm
Longevity (t_{max})	6.59 yr
Theoretical age at length, 0 (t_0)	-0.236yr
Growth constant (K)	0.46yr ⁻¹
Length at first capture (L_c)	47.11cm
Length at first sexual maturity (L_m)	70.5 cm
Age at first capture (t_c)	0.95 yr
Total mortality (Z)	2.69 yr ⁻¹
Natural mortality (M)	0.66 yr ⁻¹
Fishing mortality (F)	2.03 yr ⁻¹
Exploitation ratio (E)	0.75

The Von Bertalanffy Growth Function of *Trichiurus lepturus* sampled along the coast of Ghana from September 2018 to August 2019 can be described as follows:

$$L_t = 133.66\{1 - \exp[-0.46(t + 0.236)]\}$$

The fish attained lengths of 57.96, 85.87, 103.49, 114.62, and 121.64 cm, respectively by the end of 1, 2, 3, 4 and 5 years (Fig. 5). The maximum observed length of *T. lepturus* was 103.9 cm and using the VBGF equation, the corresponding age was estimated as 3 years.

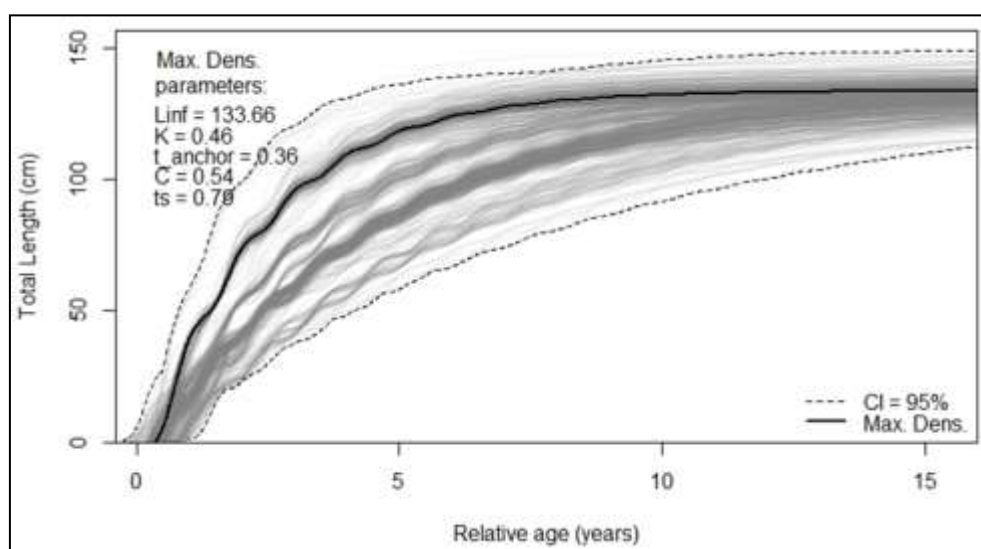


Fig 5: Von-Bertalanffy growth curve of *Trichiurus lepturus* along the coast of Ghana

The input parameters used for Virtual Population Analysis (VPA) were L_{∞} of 133.66, K of 0.46 and M of 0.66, a as 0.0002 and b as 3.3457 derived from the length-weight relationship of the species. The VPA indicated that major loss in the stock up to 37.5 cm was due to natural causes (Fig. 6). Fishes became more vulnerable to the gear after this size, and mortality due to fishing increased eventually. The highest

fishing mortality was found to be in the midlength class of 87.5 cm followed by midlength class of 72.5 cm indicating higher fishing mortality in larger length groups (Fig. 6). Higher fishing mortality was observed in the midlength classes of 52.5 to 57.5 which coincides with the modal class of the length-frequency distribution in Fig. 3.

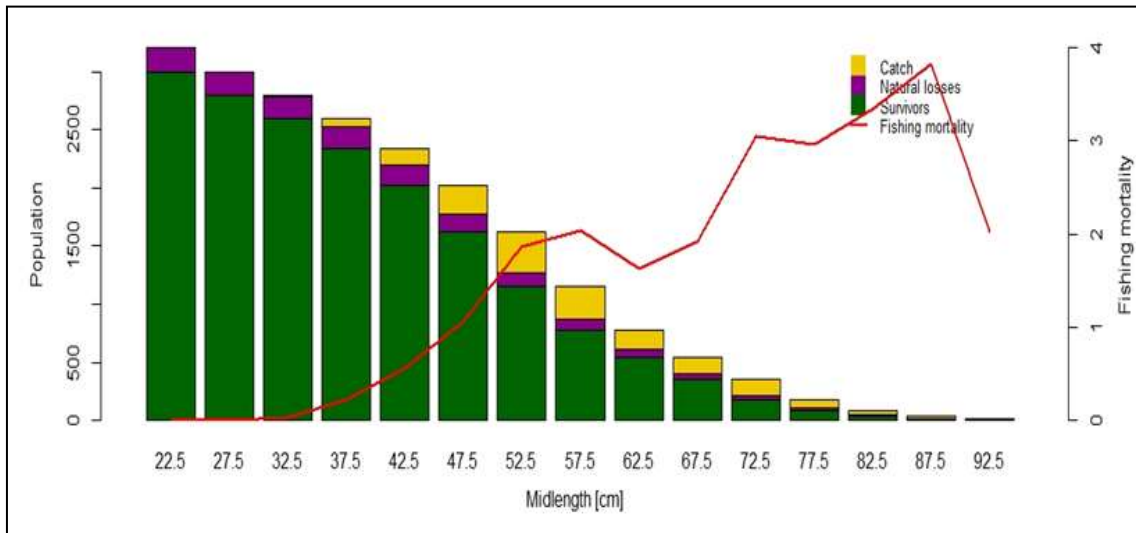


Fig 6: Length structured VPA indicating the catch, natural losses, survivors and fishing mortality of *Trichiurus lepturus*

Total length at first sexual maturity was estimated at 70.5 cm for males and 71.1 for females (Fig. 7). However gonadal development and sexual maturity was observed to commence

from 52 cm in males and 58 cm in females. All males above 82 cm and females above 80 cm were sexually mature.

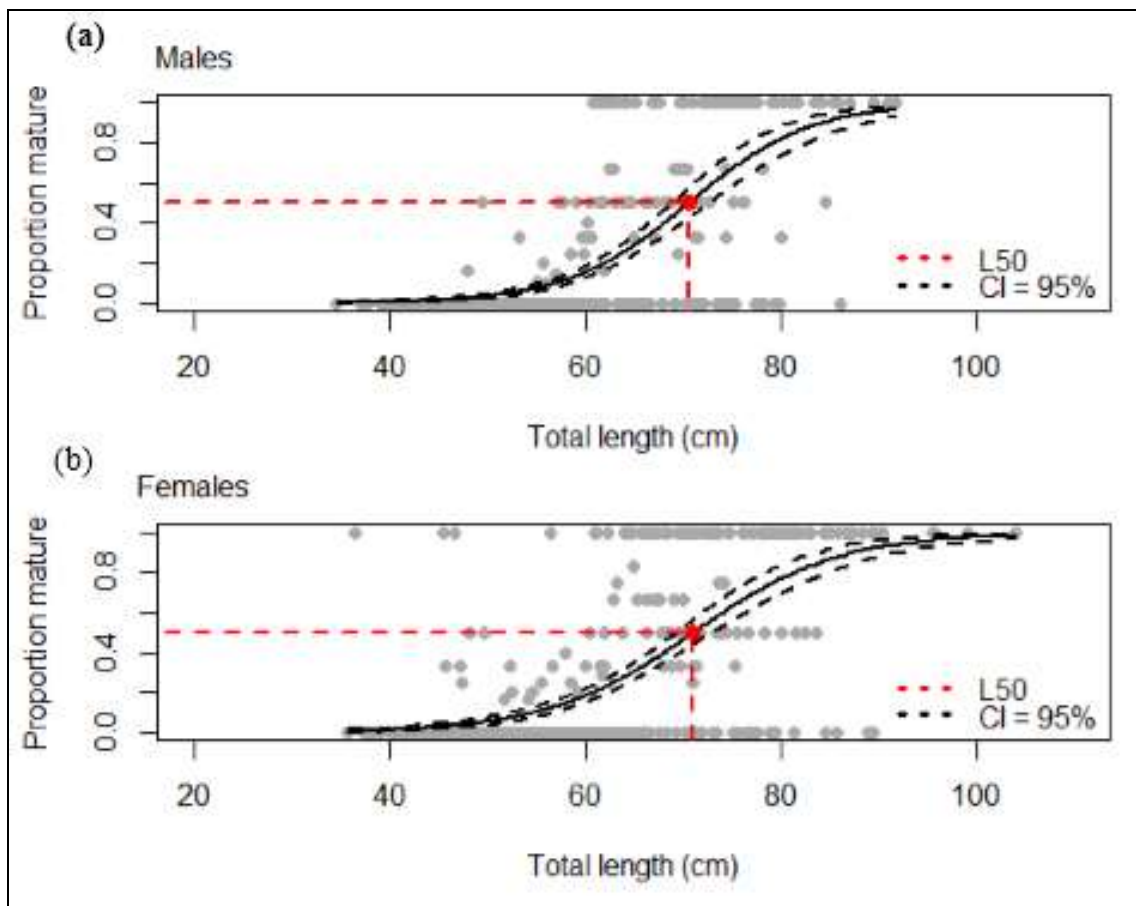


Fig 7: Length at first sexual maturity for: (a) male and (b) female *T. lepturus*

The total specimens of 1,677 of *T. lepturus* obtained comprised of 45% males; 41.5% females and 13.5% indeterminate sex. The monthly sex ratio of *T. lepturus* indicated that the females dominated the population apart

from the months of September and October, 2018 and April and August, 2019. Conversely, the overall sex ratio (M:F) of *T. lepturus* was 1.1:1 and did not differ significantly from the normal expected ratio of 1:1 of fish populations (Table 2).

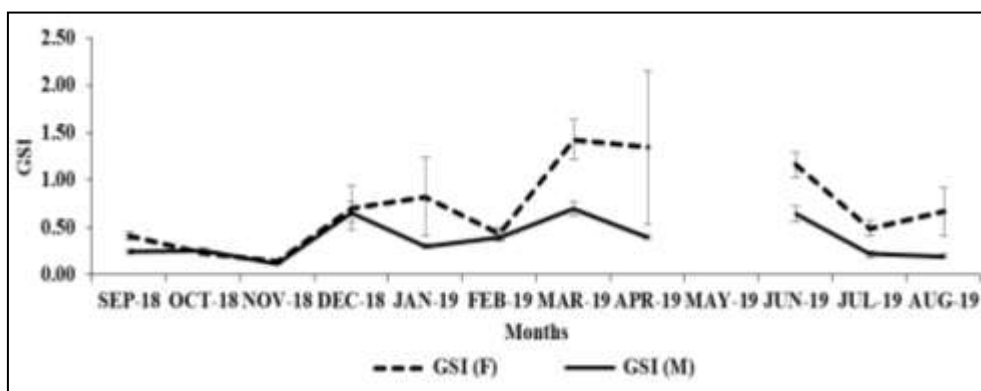
Table 2: Sex ratios of *T. lepturus* along the coast of Ghana as estimated from September 2018 to August 2019

Months	Total number	No. of males	No. of females	Sex ratio M:F	χ^2	$p = 0.05$
Sept, 18	74	51	23	2.2:1	10.595	S
October	199	125	74	1.7:1	13.070	S
November	238	105	133	1:1.27	3.294	NS
December	131	60	71	1:1.18	0.923	NS
Jan, 19	168	81	87	1:1.07	0.214	NS
February	101	49	52	1:1.06	0.089	NS
March	89	28	61	1:2.18	12.235	S
April	107	85	22	3.9:1	37.093	S
May‡		-	-	-		
June	149	73	76	1:1.04	0.060	NS
July	88	37	51	1:1.38	2.227	NS
August	107	60	46	1.3:1	1.579	NS
Total	1450	754	696	1.1:1†	2.239	NS

†indicates overall monthly sex ratio, S = significant and NS = not significant, $df = 1$
 ‡no sampling due to closed season

There was significant monthly variation in the Gonadosomatic Index (GSI) of both male and female *T. lepturus*, [$t(9) = 2.26, p = 0.008$] with females ($M = 0.59, SD = 1.30$) attaining higher values than males ($M = 0.35, SD = 0.42$) where M and SD stand for mean and standard deviation respectively. The mean GSI of the males varied from 0.12 to 0.70. The female GSI of *T. lepturus* on the other hand ranged

from 0.14 to 1.43. The pattern of GSI for the females was more or less similar to that of the males. Comparatively, the GSI of the females in general were higher than in males. Two peaks were observed in the trend of GSI of female *T. lepturus*. Of the peaks identified, the highest observed occurred in March and June 2019 whilst the lowest peak was observed in November, 2018 (Fig. 8).



Note: Data was not collected in the month of May due to closed season observed

Fig 8: Monthly mean gonadosomatic index of males and females *Trichiurus lepturus* (vertical bars represent standard errors)

Six stages of gonadal development were observed in males and five in the females. Females with ripe eggs (Stage IV) were recorded in almost all the months except in September with their peak occurrence observed in March. This suggests

an all-round spawning period with a peak spawning in March. Males with ripe gonads were absent in November and December 2018 (Fig. 9).

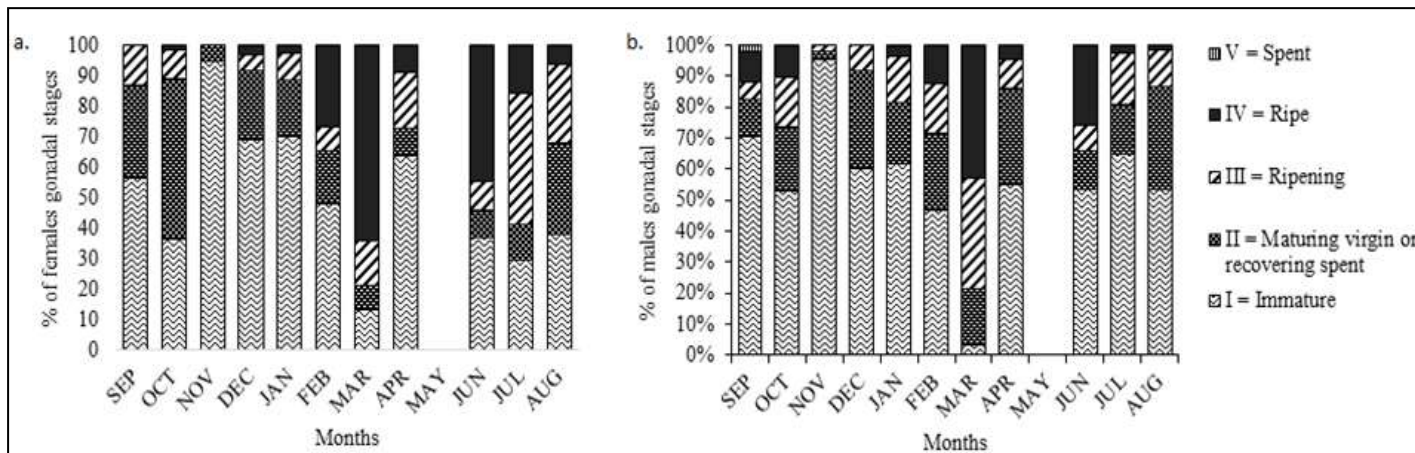


Fig 9: Monthly variation for maturity stages for females (a) and males (b) of *T. lepturus*

About 64% of the females and 43% of the males encountered within the month of March had ripe gonads. Males with spent gonads (Stage V) occurred only in September representing 2% of the various gonadal stages. Stage III males and females occurred throughout the period with the highest proportion represented in March for males (36%) and in July for the females (43%). Stages I and II males and females were present in all the months with lesser proportions occurring in the month of March for both sexes. This further suggests spawning in March.

The fecundity of *T. lepturus* was presented as a scatter plot relating total number of eggs to the total length, body weight and gonad weight of individual fish with ripe ovaries. The number of ripe eggs of *T. lepturus* ranged from 4,876 to 43,410 eggs with a mean of $17,440 \pm 1250$ eggs (mean \pm SE) based on 50 ovaries of fishes ranging in total length from 58.6 – 89.7 cm and weight 124.6 – 624.2 g. The relationship between fecundity (F) and total length (TL) of *T. lepturus* was represented as: $F = 592.99TL - 26012$ ($r = 0.50$)

The relationship between fecundity and body weight (BW) was represented as:

$$F = 39.871BW + 5164.6 \quad (r = 0.55)$$

The relationship between fecundity and gonad weight (GW) was represented as:

$$F = 1138.5GW + 9663.69 \quad (r = 0.50)$$

4. Discussion

The habitat distribution map of *T. lepturus* (Fig. 2) showed a densely populated stocks of the species in the western and central part of Ghana's coast as compared to the eastern part. This observation might be attributed to the fact that there is a wider continental shelf along the western and central coast up to 50 NM as compared to the eastern of less than 20NM as reported in the Cruise Reports of R/V Dr. Fridtjof Nansen [26]. This is further explained that, the continental shelf is characterized by an enhanced productivity and biological activity due to the input of nutrient from rivers and more importantly, from the transfer of nutrient-rich deep ocean waters during upwelling [27]. Thus, the wider the shelf, the shallower the water and the higher the productivity. Wider continental shelves teem with productivity because of the sunlight available in shallow waters. This therefore, accounts for the high numbers of *T. lepturus* in the western and central part of the coast of Ghana.

The study observed that the length composition of *T. lepturus* was characterized by a unimodal size class of 50 – 59.9 cm. Comparatively, a modal size class of 60 – 69.9 cm was observed in the Makran coast (northeast Arabian Sea) [28]. This may well be attributed to gear selectivity. Ghosh and colleagues [9] observed a maximum length of 115.9 cm off Veraval, north-west coast of India whereas 125 cm TL was reported in the same waters [10]. Cruz-Torres and colleagues [15] also reported maximum total length of 97.5 cm in Boca Del Rio, Veracruz, Mexico. In the Makran coast (northeast Arabian Sea); 129.5 cm was recorded [28]. By comparison, the maximum total length of 103.9 cm observed for *T. lepturus* in the present work is within range for the species across the globe. Females attain larger sizes and become heavier than males of the same age mostly after reaching sexual maturity [1]. This was observed in females that dominated in size classes > 90 cm. Differential growth may reflect a higher

reproductive investment by males. Also, the species *Trichiurus japonicas* exhibits the same trait where the female attain larger sizes than males [29].

The relationship between total length and body weight of *T. lepturus* along the coast of Ghana was described by the equation $BW = 0.0002TL^{3.3437}$ ($r = 0.98$) exhibiting positive allometric growth which implies that the fish increases in width more than in length. Froese [30] stated that if $b > 3$, then large specimens have increased in height or width more than in length, either as a result of a notable ontogenetic change in body shape with size, which is rare, or because most large specimens in the sample are thicker than small specimens, which is common. The latter was observed for *T. lepturus* in this study. Similar results of b values of 3.352 and 3.3237 from the length-weight relationship was also reported from the Arabian Sea Coast of Oman [31, 3]. However, a higher 'b' value was recorded in the present study as compared to 2.584 in Makran coast [28]. This variation is possibly due to factors related to ecosystem and biological phenomena like maturity stages, feeding behavior and competition for food.

The estimate of L_{∞} value of 131.25 cm for *T. lepturus* in this current study compares well to 135.09 cm and 134.1 cm reported off Veraval, north-west coast of India [10, 9] and 128.2 cm off Kakinada, east coast of India [8]. Comparatively, lower values of 116.75 cm and 114.4 cm were reported off Karnataka, south-west coast of India and in the northern Bay of Bengal respectively [11, 13].

The length at first capture (L_c) was estimated at 47.11 cm and is lower than length at first maturity (L_m) of about 70.5 cm. This indicates that the species enter the exploitation phase before attaining sexual maturity. This results in stress on spawning stock and could be addressed by enhancing their size and age at exploitation, which means that increase in mesh size of gears should be enforced to avoid the capture of young fishes [9]. The growth coefficient of 0.46 per year was same in the Arabian Sea coast of Oman [3], but different values of growth coefficient ranging from 0.29 to 0.82 were reported by other authors [32, 8, 9, 11]. Consequently, the growth performance index of 3.92 in the present study matches with that of earlier published reports [11]. The length at first capture of 47.11 cm was quite similar to that reported by the aforementioned author but higher than 14.11 cm reported by Ghosh and colleagues [9].

T. lepturus from different localities and regions mature at different body sizes. In this study, size at first maturity of *T. lepturus* was estimated as 70.5 cm for males and 71.1 cm females. Length at first maturity of *T. lepturus* was 61.2 cm in the northern Arabian sea and 59.2 cm in the Bay of Bengal [13]. A study in Kakinada, east coast of India, estimated the size at first maturity as 47.3 cm at age 7.7 months [8]. In that same study, gonadal development and sexual maturity in the species was observed from 38 cm onwards. However, higher values were encountered in other parts of the world. In Southern Brazil, an estimate of 63 to 69 cm length at first maturity was reported [1] and 71 cm in South China Sea [33]. Even higher values of 79 cm was reported in the Arabian Sea coast of Oman [3]. The differences in exploitation rates across the globe could account for the variations in length at first maturity, as fish tends to mature early when the fishing pressure is very high or when they are overexploited. A wide range of sizes at maturity in different parts of the world also demonstrate the adaptability of the ribbonfish to different environments.

Natural mortality coefficient of a fish is directly related to the

growth coefficient (K) and inversely related to the asymptotic length (L_{∞}) and the life span [34]. *T. lepturus* which had lower growth coefficient of 0.46 per year and a lifespan of 6.6 years was found to have relatively lower natural mortality coefficient of 0.67 per year. The fishing mortality (2.03) of *T. lepturus* recorded was similar to that reported by Khan [31] but higher in the Arabian seas [9]. The high exploitation ratio ($E = 0.75$) observed in this study is an indication of intensive fishing of this species and is similar to 0.73 from the South-West Coast of India [11].

It was observed from the study that females outnumbered males in general but there was no significant difference in the M:F ratio. Chi-square values indicated significant dominance by females ($\chi^2 = 2.239$, $p = 0.05$) during March which happens to be the peak breeding season (Table 2). The higher number of females in March could be due to the possibility that spent males must have left the spawning grounds before the females or perhaps the possibility that few males can contribute to the fertilization of numerous eggs considering the type of spawning exhibited by *T. lepturus*. Females of *T. lepturus* spawn more than once in a reproductive season with sex ratio favouring females, particularly in larger size classes [3, 13].

Spawning season of females can be indicated based on the changes in gonad weight in relation to the body weight which emphasizes the importance of the GSI. In this study, monthly GSI values of females of *T. lepturus* reached a peak in March to June, followed by a decline in July and a series of lower values in September to December. This suggests that ovaries were ripe and ready for spawning by March and dwindled between July and December. Hence, it could be inferred that the major breeding activity occurred during the major rainy season (April to June). The major breeding which coincides with the rainy season could be ascribed to a strategy for ensuring maximum survival of offspring as the wet season is characterized by high volume of water and availability of food. Several peaks observed in GSI trends of fish populations suggest that the fish breed more than once a year. Hence, GSI of female *T. lepturus* which exhibited several peaks indicated that the fish spawned multiple times in a year. This result concurs with the observation by Kwok and Ni [33] who reported that spawning takes place almost all year round and peaks from March to June from a study conducted in the South China Sea. A mass spawning season from May to June was reported in the Arabian Sea region [3]. Peak spawning was also observed in the west coast from April to June and along the east coast from February to June in India [35]. In this study, the monthly variation in gonadal stages validates the inference drawn on peak spawning from March to June. The proportion of spawning females (females with ripe gonads) indicated a reproductive period from February to July, 2019 with a peak activity in March.

Fecundity of *T. lepturus* ranged between 4,876 to 43,410 eggs and the average number of eggs was $17,440 \pm 1250$ eggs (mean \pm SE; $n = 50$). Khan [31] reported fecundity of *T. lepturus* in India ranging from 4,900 to 81,000 eggs. Numerous studies have been conducted on the relationship between fecundity and fish parameters such as total length, body weight and gonad weight [1, 13, 14]. Linear relationships between fecundity and the total length, body weight and gonad weight have been reported by the aforementioned authors. The values of correlation coefficient, r in the present study indicate that among the parameters identified, it is the body weight that has the closest correlation with fecundity

thus, body weight is the best index for fecundity followed by gonad weight and total length. This finding is contrary to that recorded in the coastal waters of Zamboanga del Norte, Philippines, where ovary weight was the best index for fecundity followed by body length and body weight in *T. lepturus* [14]. Fecundity in teleosts could be affected by food availability, female condition index, size and environmental conditions. Thus, for a given fish, females in better condition exhibit higher fecundity indicating that size and condition are the key parameters to properly assess fecundity at the population level.

5. Conclusion

The study concludes that the species is vulnerable to growth overfishing based on the observation that individuals are exploited before they attain maturity in Ghanaian waters. Consequently, this advocates for gear restriction of the fishery resources. It is also advisable to avoid exploiting the spawning biomass by observing closed seasons during the spawning periods.

6. Acknowledgements

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