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RESEARCH ARTICLE

Main life history traits of the largehead hairtail, *Trichiurus lepturus* (Linnaeus, 1758) from the Senegalese North coast

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Abstract. *Trichiurus lepturus* is a benthopelagic species of socio-economic importance in Senegal. Despite its intensive exploitation, there is a lack of studies on its life traits in West African waters, particularly in Senegal. This study aims to determine the biological parameters of this species in the northern coastal zone of Senegal. Samples were collected monthly from April 2015 to March 2016 in Cayar, one of the main landing sites in Senegal. A total of 354 specimens were caught with longlines. Condition factor varied between the years with a peak in May. Positive allometric growth (b = 3.24) was found for this species. The reproductive period mainly occurred from April to July, and the sizes at first sexual maturity were 831 mm and 766 mm for females and males, respectively. Absolute fecundity was highly variable (39,976.88 ± 19,793.02 oocytes). The growth parameters estimated were asymptotic length (L∞) = 134 cm and the growth coefficient (K) = 0.0016. The maximum observed age was 1 year and 7 months. These parameters could be integrated into stock assessment models, providing a better estimate of the exploitation level of this resource and aiding in the formulation of more scientifically informed management measures for sustainable exploitation.

Keywords: age, growth, otolith, reproduction, Senegal

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Introduction

Trichiurus lepturus L. is a cosmopolitan species found in warm and temperate shelf waters (Séret 1990). It is a benthopelagic species distributed between shallow and inshore waters to about a 350 m depth in offshore waters and mostly occurs in dense schools along continental shores in tropical to temperate waters (Kwok and Ni 1999, Al-Nahdi et al. 2009). *T. lepturus* move between marine and estuarine ecosystems, including inshore and deep-sea areas, depending on its life cycle stage and food demand (Kwok and Ni 1999, Ghosh et al. 2009). This adaptability can make catching it more complex as it requires varied fishing techniques adapted to these different zones. The species is a voracious carnivore with strong cannibalistic behavior. Fin fishes are the most preferred prey group in the diet of

T. lepturus, followed by crustaceans and cephalopods (Ghosh et al. 2014). Reported life-history traits of *T. lepturus* suggest generally that this species is relatively short-lived, fast-growing (Del Toro 2001), and a multiple batch spawner (Kwok and Ni 1999, Martins and Haimovici 2000, Khan 2006, Al-Nahdi et al. 2009, Ghosh et al. 2014). A maximum length and weight of 243 cm and 5 kg, respectively, with a common length of 100 cm was reported by Froese and Pauly (2024). Over the past two decades, *T. lepturus* has been reported in United Nations Food and Agriculture Organization statistics as one of the ten most landed marine species in the world (FAO 2022). The total global catch of this species increased from 167 thousand tonnes in 1950 to about 1.3–1.1 million tonnes in 2016–2020 (FAO 2018), and in 2020 was 1,144,000 tonnes (FAO 2022). In Senegal, *T. lepturus* was not consumed by the local population until the 1980s. Gradually, the species has grown in importance and has become very popular today both for local consumption and for export. Thus, the amount landed for this species is increasing significantly due to the scarcity of the usual preferential target species (Ndiaye and Diouf 2007). Landings increased from 2,453 tonnes in 2008 to 22,725 tonnes in 2013. From 2014, a gradual reduction in catches is noted, from 22,206 tonnes to 3,918 tonnes in 2020 (Marine Fisheries Department, unpublished data, S. Diouf, personal communication, March 24, 2021). This reduction in catches could be linked to a decrease in stocks. Despite the intensive exploitation of this species, studies on its life traits in West African waters, especially in Senegal, are almost non-existent. The objectives of this study are to determine length-weight relationship and condition factor, breeding season, length at first sexual maturity, and age and growth of *T. lepturus* for use in stock estimation models and fisheries management.

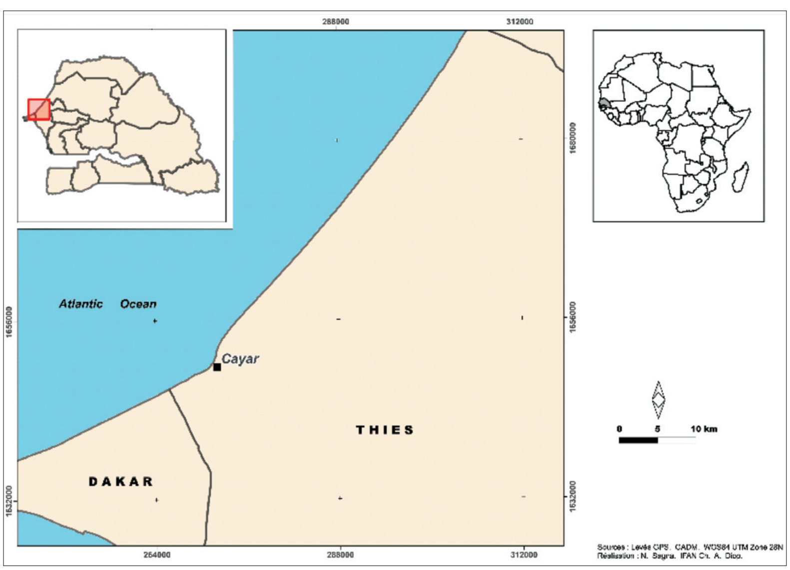

Figure 1. Sampling location of *Trichiurus lepturus* in Senegal (Cayar).

Materials and methods

Cayar is located on the Great Coast of Senegal about sixty kilometers north of Dakar. It is characterized by the presence of a deep notch called the Cayar Canyon. This underwater trench reaches more than 3,000 m in places (Dietz et al. 1968). This site also benefits from the influences of climate and upwelling phenomena that promote great biological diversity.

Samples of *T. lepturus* were collected monthly, from April 2015 to March 2016 in Cayar, one of the main landing sites of Senegal (Fig. 1).

For each month, 30 specimens were collected. At least 5 specimens per 100 mm total length class were collected. The fish were caught with longlines. Freshly caught specimens were packed in ice and transported to the laboratory. All fish (354 specimens) were measured for total length (TL ± 1 mm, between the anterior edge of the lower jaw and the end of the caudal fin), weighed for total weight (TW ± 1 g) and eviscerated weight (We ± 1 g), and sexed. The stages of sexual maturity of females were determined macroscopically according to Kwok and Ni (1999) (Table 1). For males, no maturity scale was encountered at the time of the study in widely disseminated literature in international databases. Thus, to define the maturity scale of males, macroscopic gonad characteristics were observed to assign a classification stage between 1 and 5 (Table 1)

Table 1
Trichiurus lepturus gonad maturity scale

Sexual maturity stage	Females (Kwok and Ni 1999)	Males (according to this study)
Stage 1	The ovarian wall is transparent, no eggs can be seen. Ovary filiform and short.	Gonad is transparent, filiform and short.
Stage II	Ovary cream to yellow, eggs are difficult to see. The ovary occupies about 50% of the length of the abdominal cavity.	White or slightly translucent gonad that occupies 50% of the length of the abdominal cavity.
Stage III	From yellow to orange, the oocytes are opaque and visible through the epithelium. The ovary occupies about 60-70% of the length of the abdominal cavity.	Gonad whitish and firm; no liquid flows if an incision is made. The gonad occupies about 60-70% of the length of the abdominal cavity.
Stage IV	Large ovary, filled with hydrated oocytes visible through the epithelium. Eggs in the transparent oviduct can be extruded with slight pressure. The ovary occupies about 80% of the length of the ventral cavity.	Large and soft gonad. Sperm flows at the slightest pressure on the abdomen. The gonad occupies about 80% of the length of the ventral cavity.
Stage V	Pale purple translucent ovary, narrowed and flabby.	Gonad very flaccid, exhausted and strongly vascularized.

according to the scale established by Fontana (1969). The collected ovaries were weighed (W_G ± 0.01 g). Otoliths (*Sagittae*) were then extracted, cleaned and kept dry in referenced tubes. A sub-sample of *T. lepturus* was used to estimate individual age and calculate growth rates. For each month, 3 specimens per 100 mm total length class were collected.

The length-weight relationship (LWR) was determined both for all sexes combined and separately for each sex, by fitting the length–weight data to a parabolic least-squares equation (Le Cren 1951) using the equation:

$$TW = aTL^b$$

where: a and *b* are the coefficients of the functional regression between TW and TL.

The values of parameters a and *b* were estimated with linear regression (least squares method) on log-transformed data:

$$\log TW = \log a + b \log TL \text{ (Hayes et al. 1995)}$$

Student's t-test at a 5% threshold was used to compare the value of b found in this study with the isometric value (b = 3). This test was performed according to the method of Sokal and Rohlf (1987):

$$ts = (b - 3) / SEb$$

where: ts is the t value of Student's t-test, b is the slope of the regression line, and SEb is the standard error of b.

Analysis of covariance (ANCOVA) was used to test whether the length-weight relationship differed between sexes.

Condition factor (Kc) was used to describe the general condition of the fish (Ricker 1975).

$$KC = TW/TL^3 \times 10^5$$

The homogeneity of variance was checked using Bartlett's test before analysis of variance (ANOVA). If the variance was not homogeneous ($P < 0.05$), the non-parametric Kruskal-Wallis test was used to compare monthly Kc averages.

Overall sex ratio was calculated as females:males (F:M). The sex ratio was tested statistically for significant deviations from the expected 1:1 ratio, using a χ^2 test ($\alpha = 0.05$).

The gonadosomatic index (GSI) was calculated monthly to determine the reproductive period using the formula:

$$GSI = W_G/W_e \times 100$$

Changes in the percentage of specimens with a stage equal to or greater than III and changes in the mean of GSI were monitored monthly to evaluate the seasonality of reproduction. The RGS was compared among months for the same sex using a non-parametric test (Mann-Whitney U test) because the conditions of the use of parametric tests were not respected.

Average size at first maturity (L50) was defined as the total length at which 50% of the specimens were observed to be mature (sexual maturity stage equal to or greater than III, corresponding to the irreversible development of the gonad to reach maturity) during the reproductive season. It was calculated using 50 mm size classes. L50 was estimated using a logistic function fitted by non-linear regression (quasi-Newton method, Statistica® software

$$\%M = 100/(1+e^{-a(L-L50)})$$

where: M is the percentage of mature specimens per size class (20 mm), L is the central value of each size class, and L50 are constants of the model.

Fecundity was calculated from female gonads of at least stage V during the spawning period. For each female, both gonads were weighed and a 0.05 g sub-sample was taken from one of the gonads and placed in Gilson liquid (100 ml ethanol, 9 ml glacial acetic acid, 20 ml of 60% nitric acid, 20 g mercury (II) chloride, and 875 ml distilled water). The ovocytes were separated mechanically and then manually counted under a binocular microscope. Absolute fecundity (AF) was calculated as the number of ovocytes to be released at the next spawning and the relative fecundity (RF) corresponding to the number of eggs produced per g of body weight and was obtained by reporting the number of eggs counted to the total weight (TW) of the individual.

$$AF = GW/W_{gs} \times n$$

where: n is the number of ovocytes counted in the subsample, GW is the total weight of the gonad, and Wgs is the weight of the gonad subsample.

$$RF = AF/TW$$

In order to observe both the otolith core and microincrements until the edge, the right otolith was prepared according to the technique described by Secor (1992) which includes four main stages: (1) whole otolith embedding in polyester resin (Sody 33, ESCIL, France), (2) after hardening, otolith transverse sectioning including the core with a low speed diamond saw (Isomet, BUEHLER®), (3) section mounting on microscope slides using thermofusible resin (Crystalbond® 509), and (4) grinding and polishing both faces with 1200 grit sandpaper and successive aqueous aluminium powder (3 µm, 1 µm and 0.33 µm) on polishing cloths. The final thin otolith sections were observed with a light microscope (Olympus BX 41) under transmitted light coupled with color video camera (ICC 50 HD). Magnification was 400×. D-zones were manually counted on the images: two counts were done by one reader at two different times, first from the core until the ventral edge and inversely. If no significant difference was calculated using a paired t-test for each location and the whole sample, the mean of the counts was used to estimate age.

Growth parameters were estimated for the direct readings using the von Bertalanffy growth model:

$$L = L\infty(1-e^{-K(t-t0)})$$

where: L is the mean length of an individual at time t, L∞, K, and t_0 are the parameters of the model.

Results

Length-Weight relationship

For the sampled fish, comprising 354 specimens of all sexes combined, total length ranged from 603 to 1,120 mm and weights ranged from 148.1 to 1,338 g. The logarithmic regression curve showed a very significant positive correlation between length and weight ($TW = 0.0002TL^{3.24}$, r = 0.97) (Fig. 2). The growth coefficient b = 3.24 was significantly different (Student's t-test, SEb = 0.042) from the hypothetical value 3 indicating positive allometric growth that signaled that the fish increase in weight more than in length. The logarithmic regression curve also indicated a very significant positive correlation between length and weight

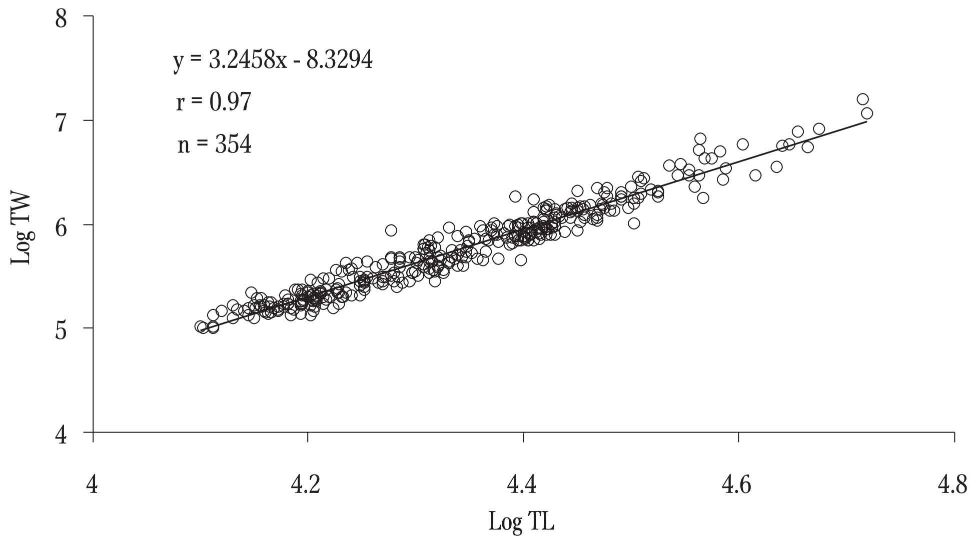

Figure 2. Logarithmic diagram of the length-weight relationship of *Trichiurus lepturus*, n = number of specimens.

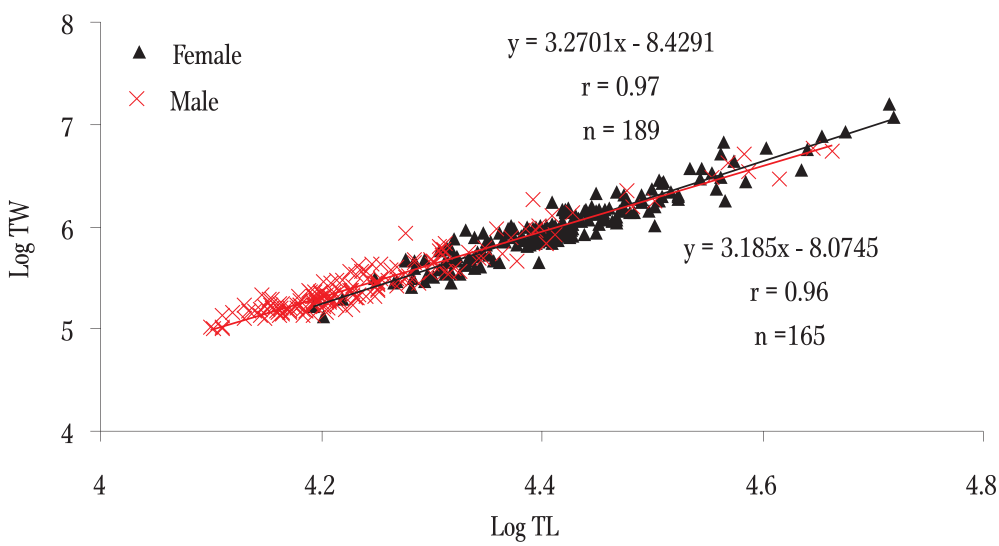

Figure 3. Logarithmic diagram of the length-weight relationship of *Trichiurus lepturus* for males and females, n = number of specimens.

for males ($TW = 0.0002TL^{3.27}$, r = 0.96) and females ($TW = 0.0002TL^{3.18}$, r = 0.97) (Fig. 3). For the length-weight comparison between sexes, the weight of females increased faster with length relative to males (Fig. 3, ANCOVA, $F_{2,925} = 3.680$, $P < 0.0001$).

Condition factor

The highest values of *T. lepturus* condition factor were noted from January to June with a maximum in May and the lowest from July to November with minima in October and November (Fig. 4). This study shows significant differences between among mean condition coefficients for May and July, August, September, October, November, December, and January (Kruskal-Wallis test, $P < 0.05$). The mean condition coefficient in June was significantly higher than in all other months except April, May, January, February, and March (Kruskal-Wallis test, $P < 0.05$)

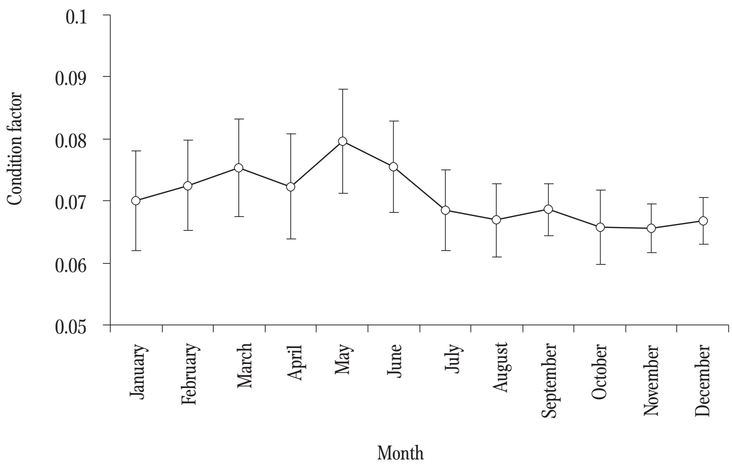

Figure 4. *Trichiurus lepturus* monthly condition factor (mean ± SD).

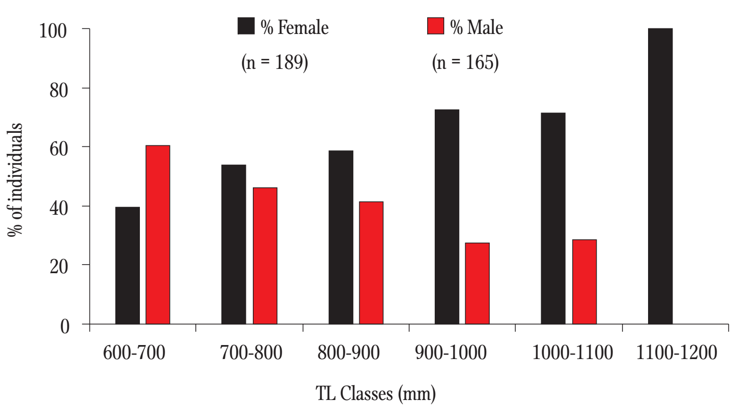

Figure 5. Sex ratio by size class of *Trichiurus lepturus*. n = number of specimens.

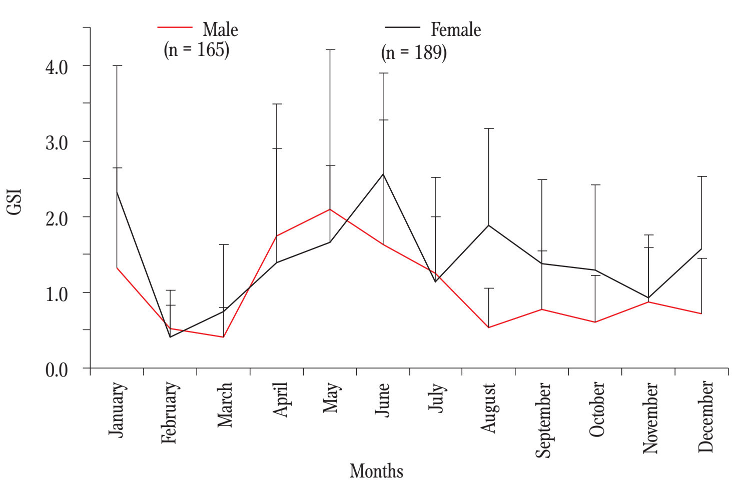

Figure 6. *Trichiurus lepturus* monthly gonadosomatic index (mean ± SD).

Reproduction

Of the 165 males and 189 females caught, 46.61% and 53.39% of the sample, respectively, the estimated sex ratio (SR) for the population was 1 male for 1.1 female. The chi-square test revealed no significant deviation from the theoretical ratio of 1 male to 1 female (P-value = 0.2). The SR was more or less balanced in the size class 700–800 mm. It was favorable to males in size class 600–700 mm and females from 900 mm (Fig. 5).

The monthly variation in GSI of *T. lepturus* indicated only one main breeding season per year from April to July. A maximum was observed in May for males and in June for females (Fig. 6). For males, the mean GSI values in April, May, June, and July were significantly higher than in all other months (Mann-Whitney test, $P < 0.05$). Females GSI values differed significantly only between April and July (Mann-Whitney test, $P < 0.05$), which suggested multiple spawning events.

The size of mature specimens varied between 646 and 1,120 mm for females and between 622 and 1,030 mm for males. Size at first sexual maturity was 831 mm for females and 766 mm for males (Fig. 7).

Fecundity

The average absolute fecundity of *T. lepturus* was estimated at 39,976.88 ± 19,793.02 oocytes (n = 32), with high variability (8,932–80,010 oocytes). Relative fertility ranged from 18.13 to 88.79 g^{-1} eggs, with an average of 67.42 ± 15.92 g^{-1} eggs (n = 32).

The relationship between absolute fertility and total length (TL) was highlighted (Fig. 8). This relationship was characterized by a linear correlation with a high coefficient of correlation (r = 0.90).

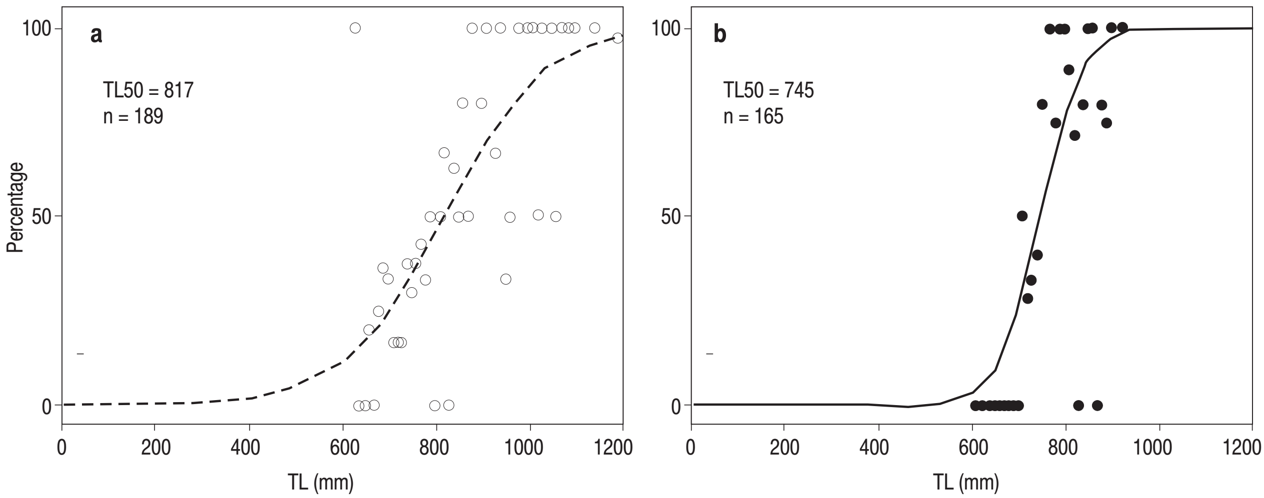

Figure 7. Size at first sexual maturity of *Trichiurus lepturus* (a = female; b = male).

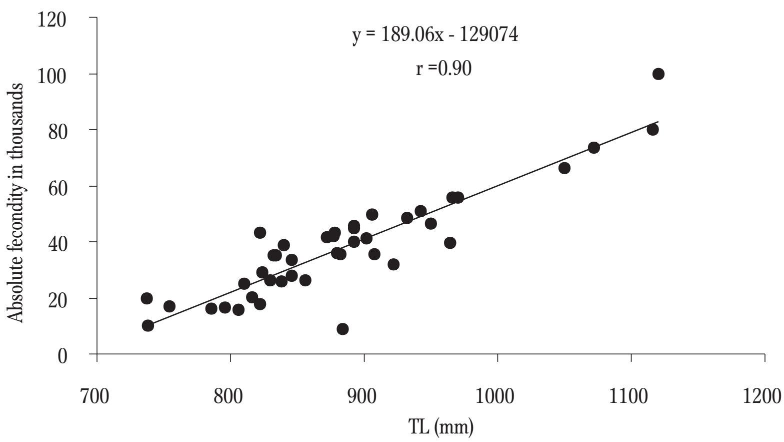

Figure 8. Relationship between absolute fecundity and total length of *Trichiurus lepturus*.

Growth

The examination of thin otolith sections revealed an alternation of dark and light concentric bands that corresponded to daily increments. A primordium was generally observed on all the otoliths examined (Fig. 9 a). However, two primordia were noted on some otoliths (Fig. 9 b). Among the 83 otoliths studied, three had two primordia. The presence of two primordia can be attributed to various environmental, physiological, and genetic factors. Due to the difficulty

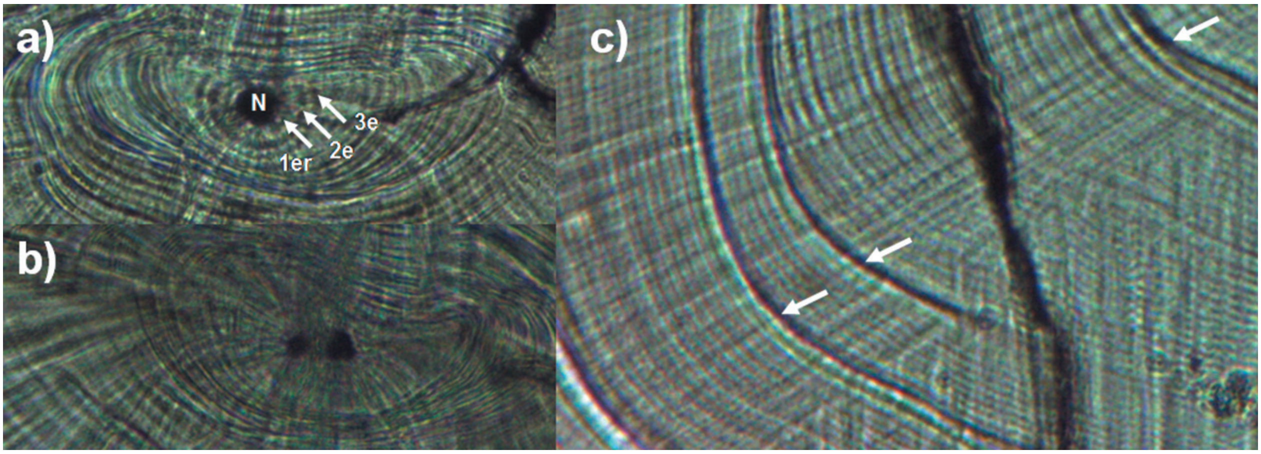

Figure 9. Thin sections of *Trichiurus lepturus* otoliths (sagittae) in transmitted light showing the nucleus (N) and early microstructures (1st, 2nd, and 3rd are the first, second and third microstructures, respectively) (a), an otolith with two primordia (b) and discontinuities (c).

in identifying the initial growth marks under these conditions, otoliths with two primordia were excluded from the analysis.

Central microstructures were clearly visible on most otoliths (Fig. 9 a). The amplitude of the microstructures varied from the center to the periphery and decreased approaching the edge of the otolith (Fig. 9 c). Discontinuities were also noted in this area (Fig. 9 c), which sometimes made interpretation difficult.

Otoliths of 80 specimens were read, among which 34 were from males and 46 from females. Individual sizes ranged from 60.3 to 107.2 cm and estimated ages ranged from 238 to 588 days. Student's t-test showed no difference between the two readings (t-test, $P > 0.05$; $t = -1.27$).

The growth parameters values were $L = 134$ cm, $K = 0.0016$ and $t0 = -189$. The maximum observed age was 1 year and 7 months. The growth curve is shown in (Fig. 10). The coefficient of determination (R_{t}) of the growth function was 0.56. The equation is:

$$L = 134(1-e^{-0.0016(t+189)})$$

Discussion

Length-Weight relationship and condition

Positive allometry was found in *T. lepturus* in this study. According to Froese (2006), if $b > 3$, then the large specimens grow more in height or width than in length. This is due either to a significant ontogenetic change in body shape, which is rare, either because the larger specimens in the sample were thicker than the smaller specimens, which was the case for *T. lepturus* in this study. Similar observations are reported in West Africa (Senegal, Gambia, Guinea Bissau and Ivory Coast) by Ecoutin and AlbAret (2003); India by Narasimham (1970), Khan (2006), Al-Nahdi et al. (2009), and Ghosh et al. (2009); Colombia by De la Hoz-M et al. (2009); Mexico by De la Cruz-Torres et al. (2014); Brazil by Viana et al. (2016); and Korea by Park and Huh (2015). Narasimham (1970), Khan (2006), and Al-Nahdi et al. (2009) estimated that the high values of the allometry coefficient b are related to the feeding habits of the species. However, some authors noted negative allometry for *T. lepturus* in Turkey (Sangun et al.

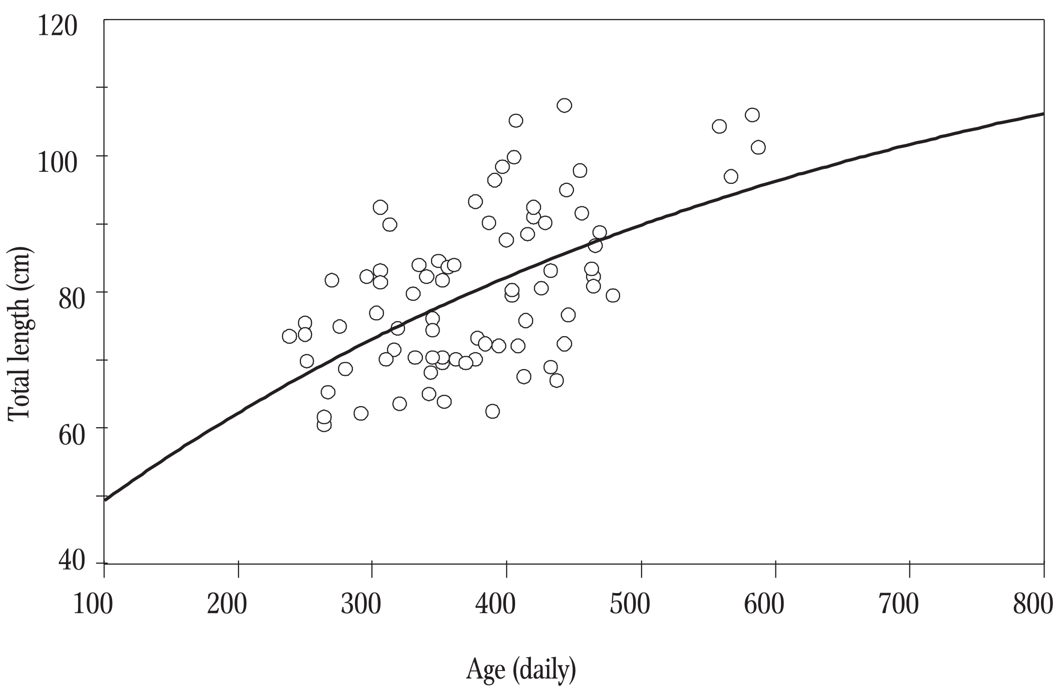

Figure 10. *Trichiurus lepturus* growth from Von Bertalanffy equation, by adjusting the nonlinear regression model (loss function).

2007), Pakistan (Tabassum et al. 2013), and India (Golpapur) (Swain 1993). Isometry was also reported by Chakraborty (1990) in India (Visakhapatnam). This variation in the b value could be related to biological phenomena such as feeding behavior and competition for food, maturity stages, and environmental factors. In this study, the weight of females increased faster with length compared to males. This observation aligns with the findings of Al-Nahdi et al. (2009), who also reported a significant difference in the length-weight relationship between females and males for *T. lepturus* in the Arabian Sea. The biological advantage of heavier body weight for female of *T. lepturus* is not yet understood; however, it may be associated with reproduction and egg production. According to some authors, the average gonadosomatic index of males was generally lower than that of females, indicating that females allocate significantly more resources to gamete production than males (Clain et al. 2023).

In Cayar, *T. lepturus* had a weak condition factor during the warm season (July-November). Periods of good conditions were observed during the cold season (December to June). Indeed, December to May corresponds to the period of upwelling on the Senegalese coast characterized by the presence of water rich in nutrients and plankton (Boely 1989, Roy et al. 1989), which means a high food availability in the environment. These results confirm the studies conducted in India (Kakinada) by Narasimham (1970) on the same species. This author showed that for *T. lepturus*, strong condition values were observed during periods of high feeding intensity. Some authors have also found a similar variation in condition coefficient values and adipose tissue amounts in the species (Sekharan 1955, Narasimham 1970).

Reproduction

A balanced sex ratio was found for *T. lepturus* in this study. However, the sex ratio gradually evolves in favor of females with increasing size. Female dominance of *T. lepturus* has been described previously in India (Ghosh et al. 2014, Rajesh et al. 2015), Oman (Al-Nahdi et al. 2009), China (Kwok and Ni 1999), and Mexico (De la Cruz-Torres et al. 2014). The results of SR in this study for *T. lepturus* do not support those of Narasimham (1994) or Satria et al. (2006), who found male dominance for *T. lepturus*. Narasimham (1994) however, noted the opposite in larger size classes. The differences between this study and those of Narasimham (1994) and Satria et al. (2006) may be due to sampling. Indeed, the studies of Narasimham (1994) covered 13 months spread over four years and those of Satria et al. (2006) covered three months, during which only 61 specimens were caught. Variations in sex ratio as a function of size and predominance of one of the sexes in older specimens appear to be relatively common phenomena in natural animal populations since they have been described in many species (Fontana 1981). The sex ratio of *T. lepturus* is generally high for males in small classes size and tends to increase for females with increasing size (Martins and Haimovici 2000). In this study, females were longer and heavier than males. According to Fontana (1981), these biological differences between males and females are due to the difference in growth rate and lifespan, which are largely determined genetically for each sex. Other factors, such as selectivity of fishing gear and vulnerability, can also hide or amplify the real variations of the sex ratio (Fontana 1981).

The study of monthly variations in mean GSI of *T. lepturus* indicated a main breeding period during the year (April - July), with a peak in May and June. Nevertheless, mature specimens are encountered almost throughout the year. This suggests that *T. lepturus* is a partial spawner species. This result is consistent with the results obtained by Bapat et al. (1982), Kwok and Ni (1999), Martins and Haimovici (2000), Khan (2006), Al-Nahdi et al. (2009), Chakravarty et al. (2013), and De la Cruz-Torres et al. (2014), which showed a main spawning period for this species. Conversely, other authors described two main breeding periods (May to June and November to January) for this species (Tampi et al. 1968). Other breeding periods, different from those found in this study, have been described in other areas. In southern Brazil, a breeding period from November to

February was described by Martins and Haimovici (2000). A spawning period from December to February was described on the west coast of India in Kakinada and Visakhapatnam by Abdussamad et al. (2006) and Chakravarty et al. (2013), respectively. Khan (2006) found a breeding season from October to May on the west coast of India in the Exclusive Economic Zone. In Mexico, De la Cruz-Torres et al. (2014) found a spawning period from January to March. All this seems to show that, like the majority of species, the reproductive periods of *T. lepturus* vary depending on environmental conditions. According to some authors, *T. lepturus* spawning does not occur regularly in warm areas of low latitudes, such as southern India (Tampi et al. 1968), the Gulf of Mexico (Sheridan et al. 1984), or southern Brazil (Bellini 1980). On the other hand, in areas with high latitudes, such as the Sea of Japan, reproduction takes place in late spring until summer. Senegal is a zone of low latitude; however, a well-defined breeding period has been identified. This difference could probably be explained by the fact that the thermal seasonality is more marked in Senegal than in these areas. For *T. lepturus*, reproduction typically occurs during periods when environmental conditions are favorable and food availability is high. This seems to reflect the species' ability to feed while reproducing. This period corresponds to the presence of upwelling on the Senegalese coast. Thus, the energy available during the peak plankton production period is used immediately for reproduction. This result corroborates with results found in southern Brazil by Martins and Haimovici (2000). These authors associated the reproduction of *T. lepturus* not only with bathymetry but also with coastal upwelling.

Moreover, the sizes at first sexual maturity estimated in this study are higher than those found for this species in different regions of the world. For example, the total length at first maturity ranged from 390 mm in southeastern Brazil (Bellini 1980) to 790 mm in Oman (Al-Nahdi et al. 2009). This wide range of size at first sexual maturity observed for *T. lepturus* in different parts of the world shows the ability of the species to adapt to different environments. However, it seems surprising that the strong fishing pressure in Senegal does not seem to have led to lowering the first maturity size of the population of *T. lepturus* in this area.

The large variability in absolute fertility observed in *T. lepturus* females (8,932–80,010 oocytes) could be related to the size of specimens. Indeed, in this study, fertility was strongly correlated with total length. This study shows a high fecundity of *T. lepturus* combined with small oocytes. This suggests that *T. lepturus* is likely to be a population-oriented species r as explained by Paugy and Lévêque (1999). No studies on the fertility of *T. lepturus* have been conducted in Senegal, but the results obtained in this study remain within the range of absolute fertility obtained in other regions. For example, absolute fertility in Brazil ranged from 3,917 eggs for a 700 mm female to 154,215 eggs for a 1,410 mm female (Martins and Haimovici 2000). It was 23,756– 208,300 north of the Arabian Sea, and 21,672–156,695 north of the Bay of Bengal (Ghosh et al. 2014). The number of oocytes was 4,900–81,000 on the northwest coast of India for females between 715 and 1209 mm in total length (Khan 2006). In Kakinada (East Coast of India), an absolute fecundity varying between 2,380 and 27,320 for specimens of 420–770 mm standard length was found by Narasimham (1994) and an average fecundity of 40,250 oocytes (for females of total length varying between 360 and 820 mm) by Abdussamad et al. (2006). Absolute fecundity of 10,395–320,712 eggs was observed in Visakhapatnam, India (Chakravarty et al. 2013). The average relative fecundity found in this study (about 67 eggs g^{-1}) confirms the results of Khan (2006) who observed an average relative fecundity of 65 eggs g^{-1} on the northwest coast of India. However, they differ somewhat from those of Ghosh et al. , according to whom, the absolute fecundity of *T. lepturus* was 158.1 and 141.6 eggs g^{-1} respectively in the North Arabian Sea and Bay of Bengal. Relative fecundity measures reproductive efficiency, indicating how effectively an organism can produce offspring relative to its size. The large variability in relative fecundity observed in this study could be attributed to the wide range of mature specimen weights. Another factor that may contribute to this variation is specimen age.

Young, mature females may not produce the same number of eggs per unit of body mass (Green 2008, Sogard et al. 2008). The results of this study also disagree with those of Abdussamad et al. (2006) who found a relative fecundity of 100.6 eggs g^{-1} in Kakinada, east coast of India and also with those of Martins and Haimovici (2000) who observed a relative fecundity of 45.9 g^{-1} eggs. These differences could be attributed to variations in environmental conditions across different areas. These varying fertility values indicate that *T. lepturus* is a highly fertile species, exhibiting significant variability in both absolute and relative fertility.

Growth

The age and growth of *T. lepturus* have been estimated in several previous studies (Table 2). However, despite the extensive bibliography on this species, no studies have focused on Africa, including Senegal. In all the studies cited, size frequencies, seasonal marks on whole otoliths or sections, and vertebrae were used to investigate the age and growth of *T. lepturus*. To our knowledge, this study is the first to utilize daily microstructures to estimate the age and growth of *T. lepturus*. The hypothesis underlying this technique is that the microstructures observed on the otoliths are deposited daily. In this study, microstructures were visible from the center to the edge of most otoliths. The amplitude of these microstructures decreased near the edge of the otolith. Discontinuities were also observed in this area, sometimes making interpretation challenging. Such discontinuities are found in all species and, according to some authors, correspond to periods of disturbance or stress (Campana and Neilson 1985, Morales-Nin and Panfili 2002). However, other research suggests that in some species, discontinuities are related to ontogenetic events (Nishimura and Yamada 1984) and in others to reproductive activity (Williams and Bedford 1974, Massou et al. 2004, Campana 2005). The causes of discontinuities on the otoliths of *T. lepturus* were not addressed in this study. Further investigations could help to better understand the factors responsible for the appearance of these discontinuities.

The asymptotic length (134 cm) obtained in this study is similar to that reported by Ghosh et al. (2009) (134.1 cm) and Avinash et al. (2014) (131.25

Table 2
Methods used till now to estimate the age and growth of *Trichiurus lepturus* worldwide (according to the international literature)

Method	Country	Study area	References
Whole otolith	China	East China Sea, Yellow Sea & Bo Hai	Misu (1958)
Otolith section	China	East China Sea	Hamada (1971)
Size frequency	India	Kakinada	Narasimhan (1976)
Whole otolith	Japan	Kii Channel	Sakamoto (1976)
Whole otolith	China	Yellow Sea & Bo Hai	Hong (1980)
Whole otolith	China	Yellow Sea	Lin and Zhang (1981)
Whole otolith	Taiwan	Costal Sea (East)	Chen and Lee (1982)
Whole otolith	Taiwan	Costal Sea (North-West)	Chen and Lee (1982)
Otolith section	China	East China Sea North	Wu et al. (1985)
Vertebral	China	Tajwan Strait	Du et al. (1988)
Whole otolith	Japan	Tsushima Waters	Hanabuchi (1989)
Size frequency	India	Bombay Waters	Chakraborty (1990)
Whole otolith	Japan	Kagoshima Bay	El-Haweet and Ozawa (1996)
Otolith section	China	South China Sea	Kwok and Ni (1999)
Size frequency and otolith section	Oman	Arabian Sea Coast	Al-Nahdi et al. (2009)
Otolith section	China	Southern East China Sea	Shih et al. (2011)

cm) in India and by Koffi et al. (2020) (138 cm) in Côte d'Ivoire, despite the differences in the techniques used. However, the asymptotic length observed in the current study is greater than that found by Chakraborty (1990) in the Arabian Sea, India (129.7 cm), Thiagarajan et al. (1992) in the Bay of Bengal, India (129 cm), Rajesh et al. (2015) southwest of the Indian coast (116.75 cm), Al-Nahdi et al. (2009) in the Arabian Sea, Oman (127 cm), and Abdussamad et al. (2006) east of the Indian coast (128.2 cm). The variation in asymptotic length observed may be related to differences in the ecological characteristics of various regions. No plateau indicating the end of growth was observed on the growth curve. The maximum age recorded in this study was 1 year and 7 months. These observations could be attributed to the high fishing pressure exerted on the species, causing specimens to be caught early during their growth phase and rarely reaching their maximum age and size. In addition, the size at first sexual maturity estimated in this study is higher than the minimum size allowed by the Senegalese Fisheries Code. Indeed, Decree no. 2016 1804 of 22 November 2016 on the application of the law no. 2015 18 of 13 July 2015 relating to the Code of Maritime Fisheries states that the minimum size of catch must be strictly 700 mm for *T. lepturus*.

Conclusion

This study is the first of its kind conducted in Senegal and West Africa and enhances our understanding of the biology of *T. lepturus*. The biometric relationships identified indicate that mass grows at a faster rate than length. The parameters of the length-weight relationship should enable the accurate estimation of weight from length and vice versa. Growth parameters and other biological characteristics can be incorporated into stock assessment models for this species, providing a more accurate estimate of resource exploitation levels in Senegal. This study advances our understanding of the biology of *T. lepturus*. Knowledge of the reproductive period, size at first sexual maturity, and current exploitation levels will offer more relevant and well-documented scientific guidance on the management measures needed to ensure its sustainable use. To consolidate the information on the life history traits of *T. lepturus*, we recommend conducting further extended studies along the West African coast. These studies should account for environmental parameters, and the identification of maturity stages should be based on histological analysis of the gonads.

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