Regional Studies in Marine Science 44 (2021) 101727

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Fishing gear selectivity on sub-adults and spawning stock of the Tarpon *Megalops atlanticus* (Actinopterygii: Megalopidae) in Northeast Brazil

Carlos Eduardo Lira dos Santos Silva [a,*], Caroline Vieira Feitosa [b], Cezar Augusto Freire Fernandes [c]

[a] Mestre em Engenharia de Pesca, Universidade Federal do Ceará, Campus do Pici, Fortaleza, Ceará, Brazil
[b] Instituto de Ciências do Mar, Universidade Federal do Ceará, Fortaleza, Ceará, Grupo de Ictiologia Marinha Tropical (IMAT), Brazil
[c] Universidade Federal do Piauí, Campus Ministro Reis Velloso, Parnaíba, Piauí, Brazil

ARTICLE INFO

Article history:
Received 2 June 2020
Received in revised form 7 November 2020
Accepted 3 March 2021
Available online 5 March 2021

Keywords:
Reproductive period
Fecundity
Diameter of oocytes
Multiple spawns
Females

ABSTRACT

The Tarpon (*Megalops atlanticus*) is a species with economic importance as a food fish and a source of income for artisanal fishers. Research regarding the reproductive biology of this species is scarce or incomplete, especially for this species in northeastern Brazil. Tarpon were caught each month near the Bitupitá district using longline fishing and arrowhead fixed traps, from October 2017 to September 2018. The Tarpon specimens were weighed, measured, and the type of fishing equipment used for the capture was noted. Gonads were obtained and evaluated macroscopically, and fixed and preserved for future microscopic analyses. The present study observed 150 females and 102 males for a total of 252 individuals. The sex ratio was 1:1.5 (M:F) and females showed a dominance in the longer length classes. Both sexes presented negative allometry ($b < 3$). The gonadosomatic index (GSI), Fulton's condition (K) values and sexual maturity indicate that the reproductive period occurs between August and November, which is during the dry season. The length at first maturity (L_{50}) presented values of 101.7 cm total length (TL) for females, 99.4 cm TL for males and 101 cm TL for both sexes grouped together. The mean fecundity was 7.5 million oocytes and the species present asynchronous oocyte development, multiple spawning periods, and continuous recruitment of oocytes from the reserve stock indicating indeterminate fecundity.

1. Introduction

The Tarpon is a migratory species distributed in the Western Atlantic Ocean from Canada to Southern Brazil and from Mauritania to Angola, and records show its occurrence in the Eastern Atlantic Ocean near Portugal, the Azores and southern France (Hureau, 1984; Saldanha and Whitehead, 1990). This species has a long life of up to 55 years (Crabtree et al., 1995) and shows slow growth, late sexual maturity, indirect larval development (leptocephalus larvae). The Tarpon is considered as an important ecological indicator for being at the top of the aquatic food chain. Increased fishing pressure and reduced habitats have depleted natural stocks and population abundance of the Tarpon (Dailey et al., 2008).

Tarpon migrate between inshore (wetlands), coastal (estuaries) and offshore marine ecosystems (Griffin et al., 2018). This fish migrates for reproduction, which occurs in areas far from the coast in clean and transparent waters with high salinity and a low presence of predators of the larvae. During the reproductive period, Tarpon form large shoals in coastal waters before migrating to offshore regions for spawning (Crabtree et al., 1992, 1997). According to Crabtree et al. (1997) and Stein III et al. (2012), Tarpon have multiple spawning periods and asynchronous oocyte development because females have ovaries with post-ovulatory follicles and oocytes at advanced vitellogenesis.

Research of this species in Brazil is scarce and has only addresses the age at first maturity and the reproductive period (Menezes and Paiva, 1966) and length–weight relationship (Menezes, 1967). Aspects of Tarpon reproductive biology such as spawning sites, age at first sexual maturity, type of oocyte development and fecundity, and sex ratio are unknown. In addition, much of the existing knowledge is based on literature from the 60's (Menezes and Paiva, 1966; Menezes, 1967).

Tarpon is an important fishing resource in northeastern Brazil as a food fish and as a source of income for artisanal fishing families. Knowledge about its reproductive biology will facilitate the implementation of a management and recovery plan of natural stocks. Therefore, the present study aimed to describe spatial and seasonal patterns of reproductive biology of the tarpon, including the description of the stages of sexual maturity, gonadosomatic

* Corresponding author.
E-mail address: ceduardosilva@alu.ufc.br (C.E.L.d.S. Silva).

https://doi.org/10.1016/j.rsma.2021.101727
2352-4855/

index, length at first maturity, fecundity and frequency of oocyte diameter.

2. Material and methods

2.1. Characterization of the study area

The present study was carried out in the Bitupitá district of the municipality of Barroquinha, Ceará state, Brazil. This region is located at the western extremity of coastal Ceará near the mouths of the Timonha and Ubatuba rivers (Araujo and Rodrigues, 2015). Estuaries of the Timonha and Ubatuba rivers and the Parnaíba River and its tributaries comprise the main water bodies of the Parnaíba Delta Marine Protected Area (MPA), as they give rise to one of the most ecologically rich estuaries in the country (Pereira and da Rocha, 2015) (see Fig. 1).

The region shows a rainy season from January to May with an average rainfall of 850 mm, and a dry season from June to December with an average rainfall of below 200 mm (Funceme, 2009). The sea water shows a temperature range of 27 to 28.5 °C and an average salinity of 43 in the dry season and 37 in the rainy season (Barletta et al., 2017; Silva et al., 2015).

2.2. Fishing gear

Fishing of the Tarpon in Bitupitá is carried out using longlines and arrowhead fixed trap. Longline fishing is performed with approximately 30 canoes. Most fishing occurs between September and November, but longline fishing of the tarpon may begin in June depending on the profitability of the catch.

The main line in longline fishing is made with a 6 mm braided multi-strand rope, of which one extremity of the line is attached to the anchor of the canoe and the other extremity is attached to another anchor. The main line can have up to 80 secondary lines of approximately 11 meters in length and made of 2.5 mm nylon with a # 17/0 circular hook attached to the end. The distance between each secondary line is approximately 17 m.

The largehead hairtail (*Trichiurus lepturus*) was the main bait for fishing Tarpon due to its shiny silver body. Longline fishing in Bitupitá occurs between Camocim, Ceará state and Caju Island, Maranhão state (Fig. 2A), with over 1000 fishing points between these two locations, referred by the fishers as holes.

There are currently 33 arrowhead fixed traps in the region of the present study (Fig. 2C). The traps vary between 400 to 700 meters in length and 6 to 12 meters in height, and each trap is managed by one fisher with a canoe. The fishers harvest the fish every day. There were 27 traps located near the beach (approximately 1 km), arranged in 4 rows perpendicular to the coastline (Fig. 2B). These traps capture few Tarpons, almost all of which are young and locally known as "pema". There were six traps located approximately 14 km from the coast and they capture Tarpons of all sizes.

2.3. Sample collection and laboratory processing

Tarpon specimens were obtained each month from October 2017 to September 2018 with the assistance of local fishers. As soon as the boats anchored on the beach, the specimens caught in the two fisheries (arrowhead fixed trap and longline) were sampled. The following information was also collected: fishing gear used for capture, sex, fork length with the aid of a measuring tape (nearest 0.01 m) and the total and gutted weights using a mechanical scale (0.1 kg). Then, the weight of the gonads (kg) was measured with a digital scale (0.01 kg).

Sex and gonadal development were evaluated by observing the gonads macroscopically. Gonadal development was classified according to Brown-Peterson et al. (2011): immature, developing, spawning capable, actively spawning, regressing and regenerating. The gonads were fixed in 10% formaldehyde and preserved in 70% alcohol.

Histological slides of the gonads were prepared at the Fisheries Bioecology Laboratory (Biopesca) of the Federal University of Piauí (UFPI) for the macroscopic evaluation according to methods described in Vazzoler (1996). A section of the gonad was dehydrated with a series of alcohol solutions (80%, 95% and 100%), diaphanized in a series of xylol solutions (alcohol + xylol in equal parts, and Xylol), and then immerse in paraffin. The paraffin blocks were sectioned to a thickness of 5 μm and the sections were stained with hematoxylin and eosin.

The slides containing a section of the gonad were examined under a trinocular microscope (Model Primo Star, Carl Zeiss, Germany) at 40, 100 and 400x magnification. The microscopic terminologies of male and female gonads proposed by Brown-Peterson et al. (2011) were used as follows:

Females: Immature: Presence of ovogonia and oocytes in primary growth (PG); In development: oocytes in PG, cortical alveoli (CA), Vtg1 and Vtg2 and possibly some atresia; Able to spawn: oocytes in Vtg3 and may show post-ovulatory follicles (POFs) in individuals with multiple spawning, atresia and hydrated oocytes (H); Actively spawning: oocytes with late germinal vesicle migration (GVM), breakdown of the germinal vesicle (BGV) and a large quantity of hydrated oocytes (H) and the presence of POFs; Regression: flaccid ovaries with vascularization and the presence of atresia, POFs and may exhibit oocytes in CA, Vtg1 and Vtg2; Regeneration: presence of ovogonia and oocytes in PG, thicker ovarian wall, atresia and POFs in resorption.

Males: Immature: presence of only primary spermatogonia (Sg1); In development: spermatocytes (St) in the lobe, Sg1 and secondary growth (Sg2), spermatocytes (Sc) in primary (Sc1) and secondary growth (Sc2); Able to sperm: spermatozoids (Sz) in the lumen of the lobes or in the sperm ducts. All stages of spermatogenesis (Sg2, Sc, St and Sz) are observed; Actively sperm: can show all stages of spermatogenesis (Sg2, Sc, St and Sz); Regression: sperm residues in the lumen of the lobes and little or no active spermatogenesis; Regeneration: presence of spermatogonia and may present a small amount of residual sperm.

2.4. Data analysis

The length classes for males and females were calculated according to Sturges (1926): $K = 1 + 3.3 * \log n$, where K = number of classes, n = sample size and range of classes (H) = TR/K, where TR = Total Range (maximum value–minimum value). Sex ratios were estimated for each month and each length class, which were compared using the Chi-square test (X^2). The length–weight ratio was estimated for both sexes and then for each sex using the equation proposed by Le Cren (1951): $W_t = a\, L_t^b$, where W_t = total weight (Kg), FL = Fork length (cm), a = curve intercept and b = allometry coefficient. The curve was fitted by the least squares method and the confidence intervals of the parameters were estimated. The value of b was tested by the t-test to see if b = 3 (Santos, 1978). The significance level was $\alpha = 0.05$.

The gonadosomatic index (GSI) was calculated using the equation described in Flores et al. (2014): GSI = G/W*100, where G = gonad weight (g) and W = gutted fish weight (g). Fulton's condition (K) was calculated using the equation described in Froese (2006): $100^*W_t/FL^3$, where W_t = total fish weight (g) and FL = fork length (cm).

Length at first maturity (L_{50}) was estimated from a logistic curve based on the relative frequency of adults in each length class (SL) according to the formula: MF = exp (a+(b)* L_t)/ (1+exp(a+(b)* L_t)), where MF = fraction of adult specimens and

Fig. 1. Map of the State of Ceará and the study site near the district of Bitupitá.

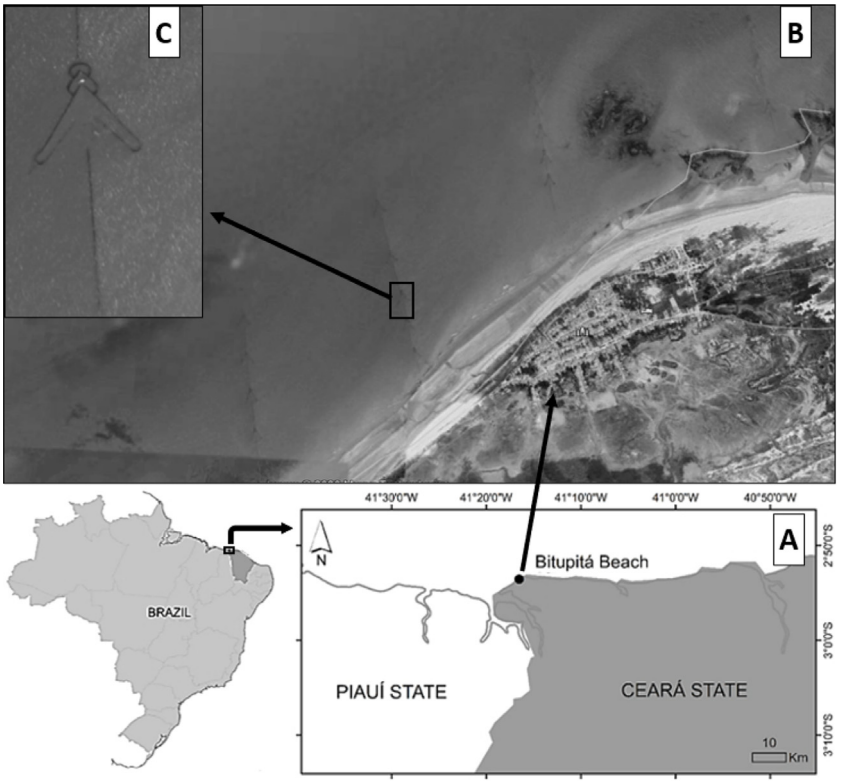

Fig. 2. (**A**) Map of the district of Bitupitá in the state of Ceará, northeastern Brazil; (**B**) Lines of traps distributed in a perpendicular manner throughout the coastal zone. Source: Google Earth. (**C**) Image of an arrowhead fixed trap.
Source: Google Earth.

FL = fork length (cm). All individuals with no vitellogenesis were considered adults. The data points were adjusted and the L_{50} value was estimated by maximum likelihood based on the data set (fork length and sexual maturity).

Fecundity was obtained by the gravimetric method proposed by Hunter and Macewicz (1985) and Murua and Saborido-Rey (2003), in which a small portion of the gonad previously identified as actively spawning was weighed on an analytical balance. Then the oocytes were counted with the aid of a Nova ZTX-E binocular stereoscope. Fecundity (F) was calculated by the equation: F=N/PP*G, where N = number of oocytes counted, PP = weight of the weighed portion (g) and G = gonad weight (g). Statistical analyses were performed using Excel® software.

To obtain the oocyte diameter, the slides containing the ovarian sections of the females identified as actively spawning were analyzed and photographed on a Primo Star trinocular microscope coupled to a 5MP Axiocam 105 camera. The diameter of 100 oocytes from each stage of development was measured using the ZEN 2 Core imaging software.

Average monthly rainfall was obtained from the Funceme website (Funceme, 2018) and the rainy and dry seasons were defined according to Funceme (2009). Data were tested for normality (Shapiro–Wilk test) and homoscedasticity (Levene's test).

Table 1
Sex ratio and number of Tarpon (*Megalops atlanticus*) sampled per month and fishing gear used in northeastern Brazil from October 2017 to September 2018.

Months	Number		Total	X^2	Sex ratio	Number	
	Females	Males			(M: F)	Fixed trap	Longline
oct/17	22	13	35	6.6*	1:1.7	19	16
nov/17	31	12	43	19.5*	1:2.6	7	41
dec/17	4	5	9	1.2	1:0.8	9	0
jan/18	4	4	8	0	1:1	8	0
feb/18	6	2	8	25.0*	1:3	8	0
mar/18	5	3	8	6.25*	1:1.7	8	0
apr/18	6	4	10	4.0*	1:1.5	10	0
may/18	14	17	31	0.9	1:0.8	31	0
jun/18	5	6	11	0.8	1:0.8	11	0
jul/18	9	6	15	4.0*	1:1.5	10	0
aug/18	18	16	34	0.35	1:1.1	20	14
sep/18	26	14	40	9.0*	1:1.9	16	24
$\sum$	150	102	252	3.63	1:1.5	157	95

*Significance level $\alpha < 0.05$.

Table 2
The length–weight ratio for females, males and for both sexes grouped together. Values of *p*, "a", "b", confidence intervals and allometric coefficient of Tarpon (*Megalops atlanticus*) caught from October 2017 to September 2018 in northeastern Brazil.

	Grouped Sexes	Males	Females
p-value	2.16E−148	5.98E−111	2.82E−118
a-value	7E−05	7.92E−05	7.97E−05
b-value	2.57	2.52	2.54
Limit superior of "a"	2.15	0.98	1.98
Limit inferior of "a"	−2.15	−0.98	−1.98
Limit superior of "b"	2.58	2.53	2.56
Limit inferior of "b"	2.55	2.51	2.53
Allometric coefficient	Negative	Negative	Negative

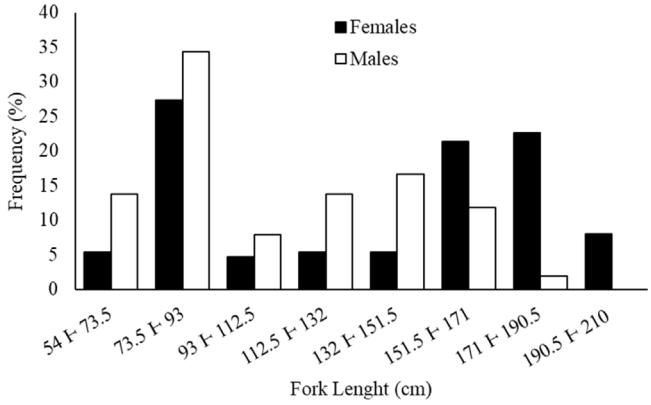

Fig. 3. Percentage of the total number of specimens per furcal length class of Tarpon (*Megalops atlanticus*) captured in Northeastern Brazil, from October 2017 to September 2018.

The Nonparametric Mann–Whitney test was applied to evaluate possible differences of the (1) sex ratio and (2) the GSI and fork length between dry and rainy seasons and fishing gears. The Nonparametric Kruskal–Wallis was used to test for differences (1) between oocyte diameters and (2) monthly variations in GSI by sex. Then, the post-hoc Mann–Whitney test was applied. These analyses were performed using PAST software (Hammer et al., 2001) and the significance level was set at α = 0.05.

3. Results

Of the 252 Tarpons examined, 150 were females (59.5%) and 102 males (40.5%). The average sex ratio during the study period was 1.0 males: 1.5 females. More females were observed than males in eight of the twelve months, of which seven months showed significant difference (Table 1). Tarpons were caught using only arrowhead fixed traps between December and July because no longline fishing was carried out during this period. Longline fishing occurred from August to November, which in September (X^2 = 21.3) and November (X^2 = 59.5) showed a higher catch of females when compared with the arrowhead fixed traps. Males were collected more with the longline than with the arrowhead fixed traps for only November (X^2 = 29). Length classes of less than 102.9 cm were captured only with the arrowhead fixed traps.

The length–weight ratio for females, males and for both sexes grouped together showed negative allometry (b <3), being 2.57 for the grouped sexes, 2.54 for females and 2.52 for males (Table 2). This indicates that there is a greater increase in length than in weight for this species (Table 2).

The furcal length of the Tarpon varied from 54 to 210 cm (mean 125.2 ± 43.5 SD) and was distributed between eight length classes with a range of 19.5 cm each (Fig. 3). Females presented lengths of 54 to 210 cm (137 ± 46.1) and males of 60 to 184 cm (107.9 ± 32.7). Weights ranged from 1.6 to 95 kg (27.1 ± 23) for both sexes, with females ranging from 1.6 to 95 kg (34.4 ± 25.3) and males ranging from 1.9 to 56 kg (16.5 ± 13.2).

Significant differences were shown for weight and length between the sexes, of which the females grow more (U=4642.5; p=1.191E-07) and are heavier than males (U=4748; *p*=3.2389E-07) (Fig. 4A). Larger individuals were also observed in the dry season (U=2893; *p*=3.1708 E-10). Regarding fishing gears, larger females (U=788.5; *p*=3.9309E-14) and males (U=239.5; *p*=9.2067E-09) were observed in longline fishing when compared to using the traps (Fig. 4B).

The average monthly gonadosomatic indices (GSI) for both sexes were higher from August to November (dry season), representing the spawning season for this species. Rainfall increases in January, which is when the rainy season begins in the region. GSI values decreased for both sexes in January, indicating the end of the reproductive period (Fig. 5). GSI values were higher for longline fishing (U=2283.5; p=2.8114E−20).

The Fulton's condition (K) for females peaked in January, when rainfall increased and resulted in a greater availability of food for the Tarpon. Males showed the highest peaks in December and February, when the reproductive period ends and the rainy season begins. After peak rainfall in February, K values were lowest in November, indicating the end of the reproductive period (Fig. 6).

Regarding sexual maturity, spawning capable (Fig. 7A) and actively spawning females (Fig. 7B) were observed from August

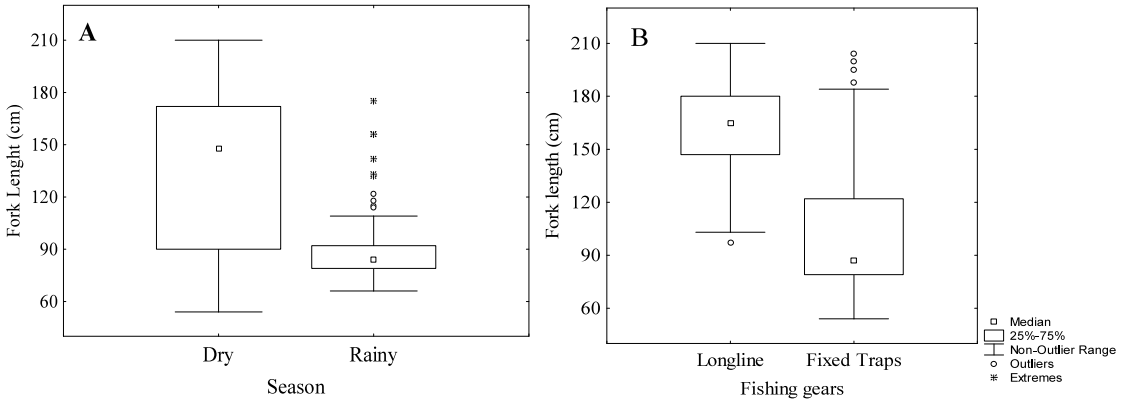

Fig. 4. Variation in fork length of Tarpon (*Megalops atlanticus*) between seasons (A) and fishing gears (B).

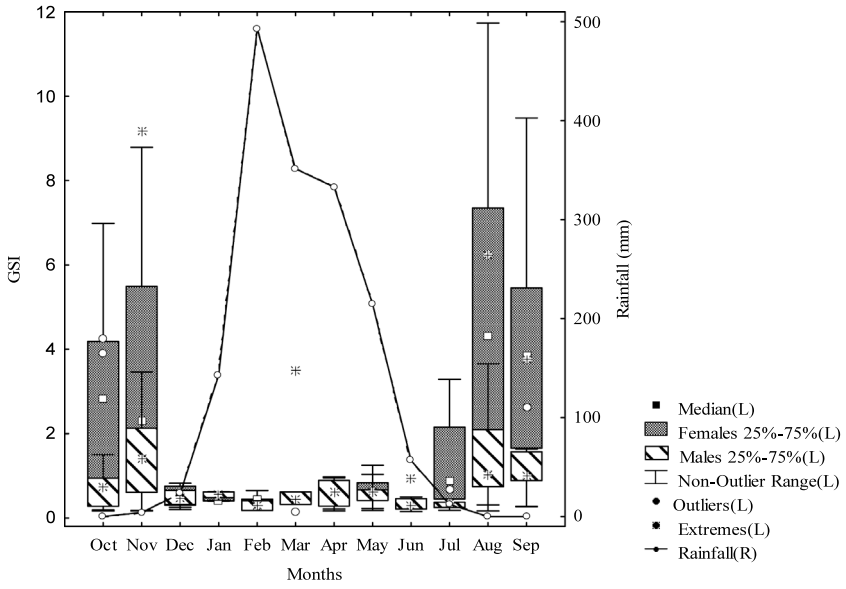

Fig. 5. Gonadosomatic index (GSI) observed each month for males and females of *Megalops atlanticus*.

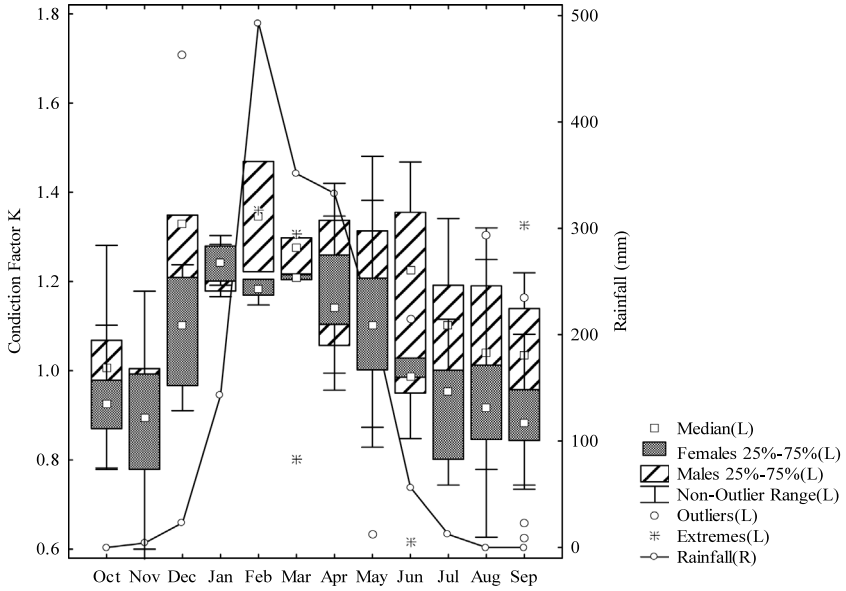

Fig. 6. Fulton's condition (K) observed each month for males and females of *Megalops atlanticus*.

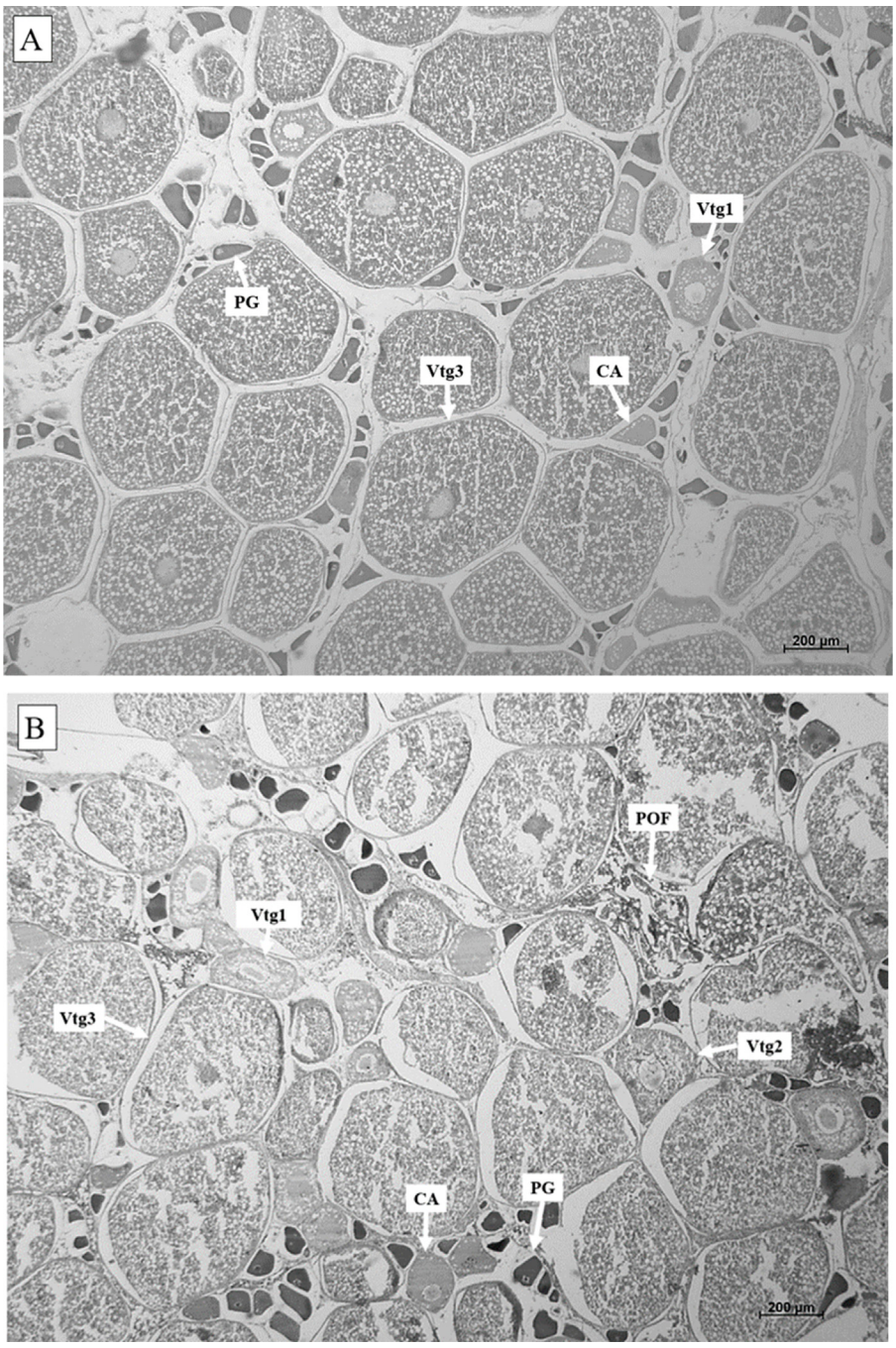

Fig. 7. Histological section of a female gonad of *Megalops atlanticus* showing (**A**) Ovary from a spawning capable female with: primary growth (PG), cortical alveoli (CA), primary vitellogenic (Vtg1) and tertiary vitellogenic (Vtg3) oocytes; (**B**) Ovary from an actively spawning female with: primary growth (PG), cortical alveoli (CA), primary vitellogenic (Vtg1), secondary vitellogenic (Vtg2), tertiary vitellogenic (Vtg3) oocytes and post-ovulatory follicles (POF) (Scale bar = 200 µm).

to November (dry season). In the rainy season, only immature or developing females were observed (Fig. 8). The actively spermiating males appeared from August to November, which coincides with the reproductive period of females.

The average length of first maturity (L_{50FL}) of Tarpon was 88.7 cm for females, 85.4 cm for males, and 87.1 cm for grouped sexes. The length of maturity (L_{100FL}) was 110 cm for females, 108 cm for males and 107 cm for both sexes grouped together (Fig. 9).

The fecundity of the Tarpon ranged between 5 and 11 million oocytes and the mean value was 7.5 million oocytes. Tarpon oocytes had a diameter ranging from 22 to 947.7 µm. Primary growth is characterized by the presence of oogonia and oocytes at primary growth (PG) (69.5 ±22.6 µm).

Secondary growth can be divided into the substages of: cortical alveolar (CA) (159.6 ±21.4 µm), which is characterized by the presence of oil vesicles in the oocyte; and vitellogenesis, which is divided into primary vitellogenesis (Vtg1) (257.9 ± 38 µm), secondary vitellogenesis (Vtg2) (382.9 ±48.3 µm) and tertiary vitellogenesis (Vtg3) (601.3 ±58.6 µm).

Oocyte maturation (OM) can be divided into three nuclear events: germinal vesicle migration (GVM), germinal vesicle breakdown (GVBD) and hydration (H) (747.3 ±55.1 µm). Ovulation is characterized by the appearance of post-ovulatory follicles (POFs), which will later be reabsorbed by the organism (Fig. 10).

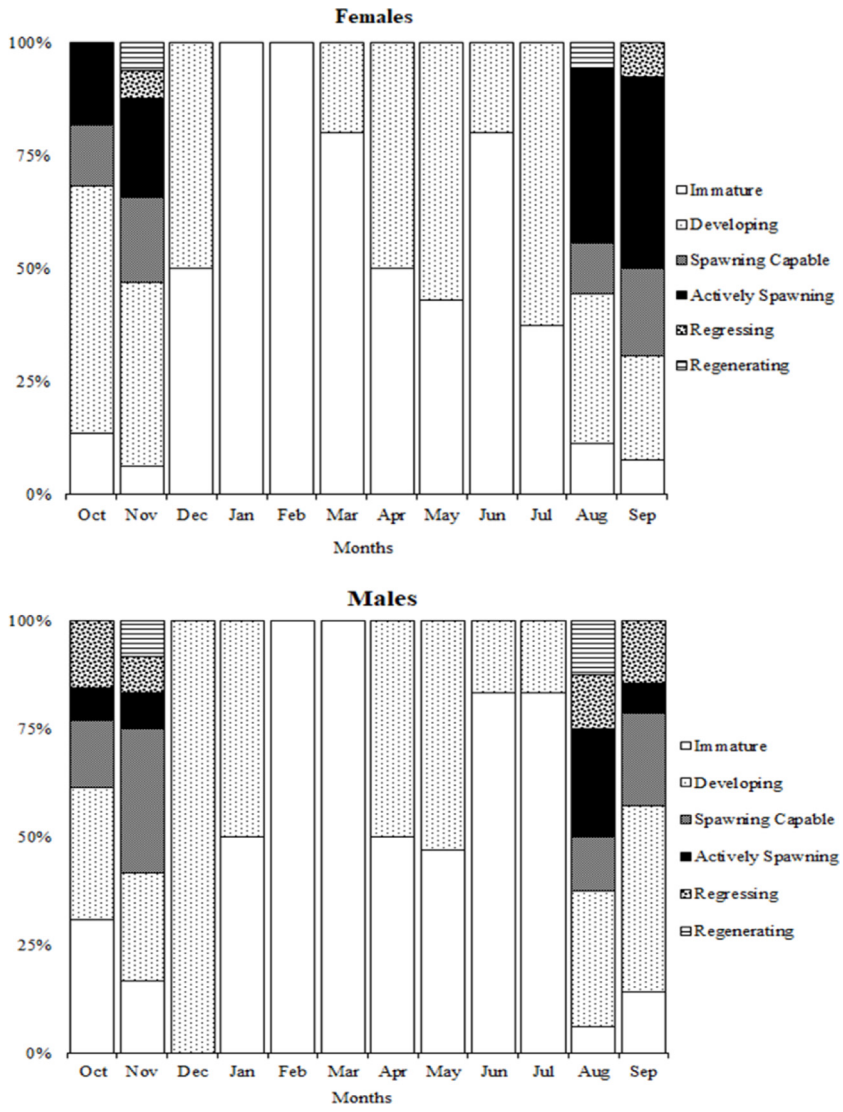

Fig. 8. Life stages (Immature, Developing, Spawning Capable, Actively Spawning, Regressing and Regenerating) observed each month for males and females of *Megalops atlanticus*.

Significant difference was shown between the oocyte development stages (H=578.7; p=8.018E-123). The Tarpon has asynchronous oocyte development and split (multiple) spawning due to the absence of gaps between stages, indicating continuous recruitment of oocytes (Fig. 11).

4. Discussion

Tarpon (*M. atlanticus*) females were larger than males, indicating sexual dimorphism. Chaverri (1993), Crabtree et al. (1997), Cyr (1991), Menezes (1967), and Menezes and Paiva (1966) also observed sexual dimorphism for Tarpons. Females are perhaps larger to produce and release as many oocytes as possible and tend to live longer than males (Cyr, 1991; Menezes and Paiva, 1966).

Female Tarpons were more frequently observed than males. Crabtree et al. (1997) found similar results when analyzing specimens caught in recreational fishing with a hook and line in South Florida, of which females were observed twice as much as males. However, Menezes and Paiva (1966) observed an alternating occurrence of the two sexes between months when fishing with arrowhead fixed traps near the Almofada beach of the State of Ceará.

The alternating of sex ratios of the Tarpon is perhaps influenced by the fishing gear. More specifically, fishing corrals are fixed traps that capture individuals of all sizes and sexes near the coast while the longline is more selective, capturing larger Tarpons on the high seas near the breeding grounds. Therefore, the selectivity of the fishing gears illustrates the ontogeny and habitat shifts of this migratory species. Ault et al. (2008) describe two types of emigrations of the Tarpon, of which on is during the planktonic larval phase and the other is during the adult phase of the fish. Tarpon larvae are transported passively by ocean currents while adults migrate actively for feeding or breeding purposes.

In the present study, Tarpon individuals collected in the longline gear showed higher GSI scores. This is probably because the longlines are set near supposed spawning areas of the Tarpon in the region. Spawning sites of the Tarpon are unknown, but it is suggested to occur in deep water after shoals migrate from shallow areas Baldwin and Snodgrass (2008). Crabtree et al. (1992) described that mature Tarpons in the Gulf of Mexico enter coastal waters to feed and form large pre-breeding aggregations. They aggregate about 2 to 5 km from the coast before moving to more distant sites to spawn. Luo et al. (2020) reported that spawning

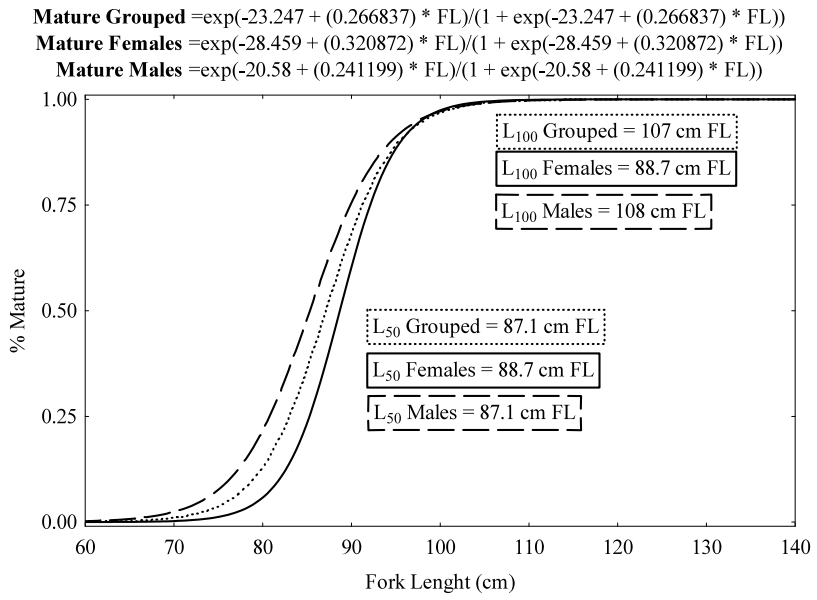

Fig. 9. Length at first maturity (L_{50}) and length at maturity (L_{100}) for both sexes grouped together (dotted line), females (full line) and males (dashed line) of *Megalops atlanticus*.

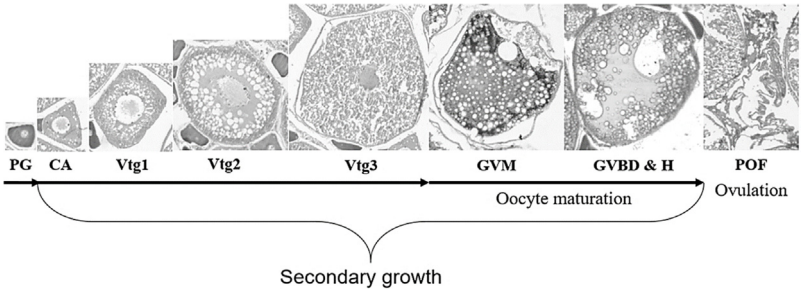

Fig. 10. Progression of oocyte development of females of *Megalops atlanticus*.

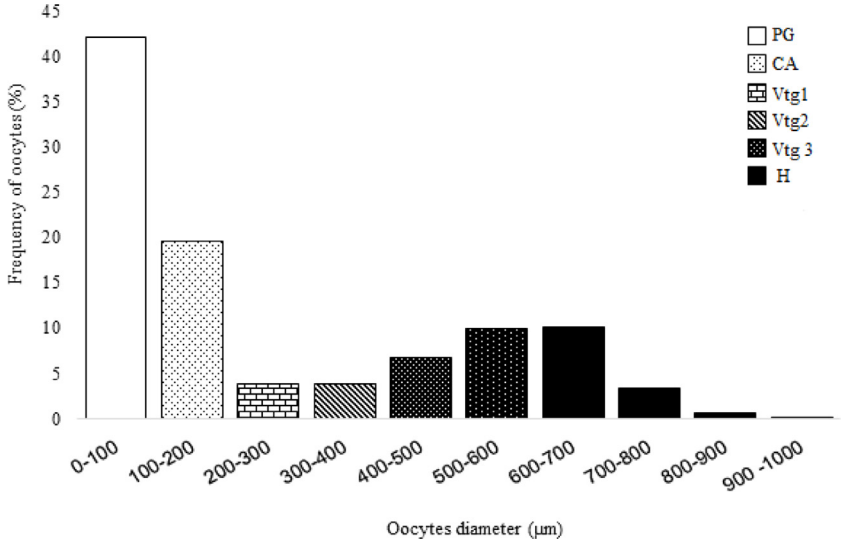

Fig. 11. Frequency of oocyte diameters of actively spawning females of *Megalops atlanticus*.

can occur in areas of continental slopes with depths varying from 100 to 200 m, temperatures around 26 ± 2 °C and a salinity of 36. Findings of the previous research corroborate observations in the present study when considering that the Tarpon captured in the arrowhead fixed traps have smaller GSI and are probably feeding and forming reproductive aggregations while the Tarpons captured by longline in the "holes" are reproducing.

The stages of sexual maturity and the GSI suggest that the spawning season of Tarpon in Northeastern Brazil occurs between August and November, coinciding with the dry season

of the region. Menezes and Paiva (1966) showed similar findings for Tarpon in this region. However, Chaverri (1993) and Crabtree et al. (1997) describe that spawning occurs throughout the year near Costa Rica. Studies conducted in Florida and the Gulf of Mexico (Crabtree et al., 1992, 1995, 1997; Cyr, 1991; Smith, 1980), North Carolina (Tucker and Hodson, 1976) and Cuba (Breder Jr, 1944) showed that spawning occurs between April and August, which corresponds to spring and summer in the northern hemisphere.

Another factor that corroborates that the Northeast region of Brazil is a spawning area for the Tarpon is the presence of young individuals in rivers and coastal lagoons (Araujo Santos, 2016; Fernandes et al., 2017). Furthermore, environmental conditions are favorable for the development of Tarpon. The ocean water shows little variation in temperature (27–28.5° C) and the salinity is higher in the dry period (43) and lower during the rainy period (37) (Barletta et al., 2017; Silva et al., 2015).

The end of the Tarpon reproductive period coincides with the beginning of the rainy season in the region. The Tarpons then migrate toward more transparent waters and with higher temperatures. Menezes and Paiva (1966) and Menezes (1967) suggest that shoals of Tarpons arrive in coastal waters of the state of Ceará during the period of low rainfall (Dry Season) for reproduction. After the reproductive period and at the beginning of the rainy season, adults migrate to more distant areas of the coast while younger individuals remain. Luo et al. (2020) suggested that some sexually mature Tarpons perform long seasonal migrations over thousands of kilometers while others have short local migrations. Tarpon in the southeastern United States also exhibit permanence and a diversity of migratory movements in coastal waters of the region (Griffin et al., 2018).

Tarpon of the present study showed high fecundity, which was also reported in previous studies (Beebe and Tee-Van, 1928; Nichols, 1929; Babcock, 1951; Cyr, 1991; Crabtree et al., 1997). According to Cyr (1991), the specific fecundity for the calculated weight is 204,019 (± 82,729) oocytes per kg of adult body weight. Hence, the Tarpon is considered as highly fertile and that larger and heavier specimens proportionally produce more oocytes. Small diameter of oocytes, the presence of all stages of oocyte development during the reproductive period, and the absence of a gap between the different oocyte stages were also observed in the present study. These characteristics indicate continuous recruitment of oocytes from the reserve stock (Hunter and Macewicz, 1985). Nichols (1929) described the Tarpon oocytes as excessively small (between 600 and 750 μm in diameter) and extremely numerous; Spotte (2016) observed oocytes of two size ranges, of 300-500 μm and 600-900 μm; and Crabtree et al. (1997) observed previtellogenic (20-200 μm) and vitellogenic oocytes (500 to 900 μm), oocytes with migratory nuclei (∼900 μm) and some hydrated oocytes (∼1000 μm).

The Tarpon has multiple spawning periods during the dry months when considering the simultaneous presence of post-ovulatory follicles, oocytes at vitellogenesis and hydrated oocytes in mature breeding females. Crabtree et al. (1997) recorded similar findings in Florida and Costa Rica waters, of which the presence of females with ovaries containing post-ovulatory follicles (POF) and oocytes at advanced vitellogenesis suggest multiple spawning periods. According to Wallace and Selman (1981) and Hunter et al. (1985), oocyte maturation and vitellogenesis are continuous during the reproductive period of species that have multiple spawning, in which one spawning batch is produced while another batch is developing for the next spawning. Nevertheless, multiple spawning periods may enable a greater survival of the species by increasing the number of oocytes to be released into the environment during the spawning season, thus avoiding competition among younger individuals.

The present study provides new data regarding the reproductive biology of *Megalops atlanticus* in northeastern Brazil. This species shows sexual dimorphism and a higher frequency of females. The reproductive period of the Tarpon in this region occurs between the months of August and November (dry season), with the species showing asynchronous oocyte development and multiple spawning periods. Specimens obtained from fishing with the arrowhead fixed traps were below the L_{50}, whereas those collected from longline fishing were considered as adults. Hence, fishing with the longline method occurs near the spawning sites.

CRediT authorship contribution statement

Carlos Eduardo Lira dos Santos Silva: Specimen collections, Fish histology and reproduction analyses, Preparation of spreadsheets, Data analysis, Writing of the manuscript. **Caroline Vieira Feitosa:** Support on fish histology and reproduction analyses, Evaluation, Manuscript discussion and review. **Cezar Augusto Freire Fernandes:** Master's dissertation advisor, Assistance in data analysis and interpretation, Manuscript review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Authors of the present study would like to thank CNPq (National Council for Scientific and Technological Development), Brazil for supporting this research. To the Graduate Program in Fishery Engineering (PPGEP) of the Federal University of Ceará (UFC). To the members of the Fishery Bioecology Laboratory (BIOPESCA) of the Federal University of Piauí (UFPI). To the fishermen of Bitupitá beach for their collaboration.

References

Araujo, A.G.P., Rodrigues, L.C., 2015. Vaqueiros do Mar de Bitupitá, Ceará: a pesca de curral e os direitos de populações tradicionais. 14ª Reunião de antropólogos do norte e nordeste, Maceió, Alagoas, Brasil, 24 pp. http://www.repositorio.ufc.br/h{and}le/riufc/21588.

Araujo Santos, G.A., 2016. Appendix H Preliminary report on Tarpon culture (*Megalops atlanticus* in excavated ponds and its [the Tarpon's] occurrence in lagoons on the coast of Tutóia–Ma [Maranhão State]. In: Spotte, S. (Ed.), Tarpons: Biology, Ecology, Fisheries. pp. 277–278.

Ault, J.S., Humston, R., Larkin, M.F., Perusquia, E., Farmer, N.A., Luo, J., Zurcher, N., Smith, S.G., Barbieri, L.R., Posada, J.M., 2008. Population dynamics and resource ecology of Atlantic Tarpon and Bonefish. In: Ault, J.S. (Ed.), Biology and Management of the World Tarpon and Bonefish Fisheries. CRC Press, Boca Raton, pp. 217–258. http://dx.doi.org/10.1201/9781420004250.sec3.

Babcock, L.L., 1951. The Tarpon: A Description of the Fish with Some Hints on its Capture, fifth ed. Privately Printed, Buffalo, p. 157.

Baldwin, J.D., Snodgrass, D., 2008. Reproductive biology of atlantic tarpon *megalops atlanticus*. In: Ault, J.S. (Ed.), Biology and Management of the World Tarpon and Bonefish Fisheries. CRC Press, Boca Raton, pp. 195–201.

Barletta, M., Lima, A.R., Dantas, D.V., Oliveira, I.M., Neto, J.R., Fernandes, C.A., Farias, E.G.G., Filho, J.L.R., Costa, M.F., 2017. How can accurate landing stats help in designing better Fisheries and environmental management for Western Atlantic Estuaries?. In: Coastal Wetlands: Alteration and Remediation. Springer, Cham, pp. 631–703.

Beebe, W., Tee-Van, J., 1928. The fishes of port-au-prince Bay, Haiti. New York Zool. Soc. 10 (1), 279.

Breder Jr, C.M., 1944. Materials for the study of the life history of *Tarpon atlanticus*. Zoologica 29 (19), 217–252.

Brown-Peterson, N.J., Wyanski, D.M., Saborido-Rey, F., Macewicz, B.J., Lowerre-Barbieri, S.K., 2011. A standardized terminology for describing reproductive development in fishes. Mar. Coast. Fish. 3 (1), 52–70. http://dx.doi.org/10.1080/19425120.2011.555724.

Chaverri, D.C., 1993. Aspectos biométricos de una población de sábalo, Megalops atlanticus (Pisces: Megalopidae). Rev. Biol. Trop. 41, 13–18. http://dx.doi.org/10.1002/9781119185543.app4.

Crabtree, R.E., Cyr, E.C., Bishop, R.E., Falkenstain, L.M., J.M., Dean., 1992. Age and growth of Tarpon, Megalops atlanticus, larvae in the eastern Gulf of Mexico, with notes on relative abundance and probable spawning areas. Environ. Biol. Fishes 35 (4), 361–370. http://dx.doi.org/10.1007/BF00004988.

Crabtree, R.E., Cyr, E.C., Chaverri, D.C., Mclarney, W.O., Dean, J.M., 1997. Reproduction of Tarpon, Megalops atlanticus, from Florida and Costa Rican waters and notes on their age and growth. Bull. Mar. Sci. 61 (2), 271–285.

Crabtree, R.E., Cyr, E.C., Dean, J.M., 1995. Age and growth of Tarpon, Megalops atlanticus, from South Florida waters. Fish. Bull. 93 (4), 619–628.

Cyr, E.C., 1991. Aspects of the Life History of the Tarpon, Megalops Atlanticus, from South Florida (Doctoral dissertation). University of South Carolina, Columbia, p. 138.

Dailey, W., Landry, J.R., A. M., Kenyon, II, F.L., 2008. The Louisiana recreational Tarpon fishery. In: Ault, J. (Ed.), Biology and Management of the World Tarpon and Bonefish Fisheries. CRC Press, Boca Raton, pp. 78–89. http://dx.doi.org/10.1201/9781420004250.ch3.

Fernandes, C., Gondolo, G., Magalhães, W., Cunha, E., 2017. The Artisanal Fisheries for Tarpon (*Megalops atlanticus*) in Brazil: Conflicts between social and ecological applications. In: TARPON and BONEFISH SYMPOSIUM, sixth ed. Weston, FL.

Flores, A., Wiff, R., Díaz, E., 2014. Using the gonadosomatic index to estimate the maturity ogive: application to Chilean hake (*Merluccius gayi gayi*). ICES J. Mar. Sci. 72 (2), 508–514. http://dx.doi.org/10.1093/icesjms/fsu155.

Froese, R., 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. J. Appl, Ichthyol. 22 (4), 241–253. http://dx.doi.org/10.1111/j.1439-0426.2006.00805.x.

Funceme, 2009. Para Entender Melhor a Previsão Meteorológica para a Estação Chuvosa no Ceará. Fundação Cearense de Meteorologia e Recursos Hídrico - FUNCEME, p. 20.

Funceme - Fundação Cearense de Meteorologia e Recursos Hídrico, 2018. Calendário das Chuvas no Estado do Ceará. Posto Barroquinha.

Griffin, L.P., Brownscombe, J.W., Adams, A.J., Boucek, R.E., Finn, J.T., Heithaus, M.R., Rehage, J.S., Cooke, S.J., Danylchuk, A.J., 2018. Keeping up with the Silver King: Using cooperative acoustic telemetry networks to quantify the movements of Atlantic Tarpon (*Megalops atlanticus*) in the coastal waters of the southeastern United States. Fish. Res. 205, 65–76. http://dx.doi.org/10.1016/j.fishres.2018.04.008.

Hammer, Ø., Harper, D.A., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron. 4 (1), 9, https://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Hunter, J.R., Lo, N.C.H., Leong, R.J.H., 1985. Batch fecundity in multiple spawning fishes. In: Lasker, R. (Ed.), An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, Engraulis Mordax. NOAA Technical Report NMFS 36. pp. 67–77.

Hunter, J.R., Macewicz, B.J., 1985. Measurement of spawning frequency in multiple spawning fishes. NOAA Tech. Rep. NMFS 36, 79–94.

Hureau, J.C., 1984. Megalopidae. In: Whitehead, P.J.P., Bauchot, M.L., Hureau, J.C., Nielsen, J., Tortonese, E. (Eds.), Fishes of the North-Eastern Atlantic and the Mediterranean. 1, UNESCO, pp. 226–227.

Le Cren, E.D., 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). J. Anim. Ecol. 20 (2), 201–219. http://dx.doi.org/10.2307/1540.

Luo, J., Ault, J.S., Ungar, B.T., Smith, S.G., Larkin, M.F., Davidson, T.N., Bryan, D.R., Farmer, N.A., Holt, S.A., Alford, A.S., Adams, A.J., Humston, R., Marton, A.S., Mangum, D., Kleppinger, R., Requejo, A., Robertson, J., 2020. Migrations and movements of atlantic tarpon revealed by two decades of satellite tagging. Fish Fish. 21 (2), 290–318. http://dx.doi.org/10.1111/faf.12430.

Menezes, M.F., 1967. Relação comprimento-peso do camurupim, Tarpon atlanticus (Valenciennes), no nordeste brasileiro. Arq. Est. Biol. Mar. Univ. Fed. Ceará, Fortaleza 7 (1), 101–102. http://dx.doi.org/10.32360/acmar.v7i1.33019.

Menezes, M.F., Paiva, M.P., 1966. Notes on the biology of Tarpon, Tarpon atlanticus (Cuvier & Valenciennes), from coastal waters of Ceará, Brazil. Arg. Est. Biol. Mar. Uni. Fed. Ceará, Fortaleza 6 (1), 83–98. http://dx.doi.org/10.32360/acmar.v6i1.322.

Murua, H., Saborido-Rey, F., 2003. Female reproductive strategies of marine fish species of the North Atlantic. J. Northwest Atlantic Fish. Sci. 33, 23–31. http://dx.doi.org/10.2960/J.v33.a2.

Nichols, J.T., 1929. The Fishes of Porto Rico and the Virgin Islands. In: Scientific Survey of Porto Rico and the Virgin IslandS. New York Academy of Sciences, New York, pp. 161–535.

Pereira, A.M.L., da Rocha, F.M.R., 2015. A pesca no estuário do Timonha e Ubatuba (PI/CE). Comissão Ilha Ativa. Sieart, Parnaíba, p. 98.

Saldanha, L., Whitehead, P.J., 1990. Megalopidae. In: Quero, J.C., Hureau, J.C., Karrer, C., Post, A., Saldanha, L. (Eds.), Checklist of the Fishes of the Eastern Tropical Atlantic (CLOFETA), Vol. 1. JNICT, Lisbon. SEI, UNESCO, Paris, pp. 120–121.

Santos, E.P., 1978. Dinâmica de populações aplicada à pesca e piscicultura. HUCITEC/EDUSP, São Paulo, p. 129.

Silva, C.E.L.S., Vieira, R., Kemenes, A., 2015. Monitoramento da qualidade da água no estuário dos rios Timonha e Ubatuba (PI/CE). In: Pereira, A.M.L., da Rocha, F.M.R. (Eds.), A pesca no estuário do Timonha e Ubatuba (PI/CE). Comissão Ilha Ativa, Sieart, Parnaíba, pp. 15–25.

Smith, D.G., 1980. Early larvae of the Tarpon, Megalops atlanticus Valenciennes (Pisces: Elopidae), with notes on spawning in the Gulf of Mexico and the Yucatan Channel. Bull. Mar. Sci. 30 (1), 136–141.

Spotte, S., 2016. Tarpons: Biology, Ecology, Fisheries. John Wiley & Sons, p. 347.

Stein III, W., Brown-Peterson, N.J., Franks, J.S., O'Connell, M.T., 2012. Evidence of spawning capable Tarpon (*Megalops atlanticus*) off the Louisiana coast. Gulf Caribbean Res. 24 (1), 73–74. http://dx.doi.org/10.18785/gcr.2401.09.

Sturges, H.A., 1926. The choice of a class interval. J. Am. Stat. Assoc. 21 (153), 65–66. http://dx.doi.org/10.1080/01621459.1926.10502161.

Tucker, J.W., Hodson, R.G., 1976. Early and mid-metamorphic larvae of the Tarpon, Megalops Atlantic, from the Cape Fear River Estuary, North Carolina, 1973–74. Chesapeake Sci. 17 (2), 123–125. http://dx.doi.org/10.2307/1351054.

Vazzoler, A.E.A.M., 1996. Biologia da reprodução de peixes teleósteos: teoria e prática. Eduem, Maringá, p. 169.

Wallace, R.A., Selman, K., 1981. Cellular and dynamic aspects of oocyte growth in teleosts. Am. Zool. 21 (2), 325–343. http://dx.doi.org/10.1093/icb/21.2.325.