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Scientific Article

Quantitative indicators of the reproductive biology of adult specimens of *Centropomus undecimalis* (Teleost: Centropomidae) obtained from commercial fishermen in the Parnaíba Delta Environmental Protection Area, north coast of Brazil

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ABSTRACT

Centropomus undecimalis (popularly known as common snook) is a very important resource for commercial and recreational fishing. This study aimed to evaluate quantitative indicators of the reproductive biology of *C. undecimalis* in the Parnaíba Delta Environmental Protection Area (Brazil). The parameters were analyzed at the different stages of the reproductive cycle of 155 specimens, 135 (87.10%) males and 20 (12.90%) females. The results showed positive allometric growth for females and negative allometric growth for males. The sex ratio was 1:6.75 (females: males). The first estimated maturation (L50) was 57.21 cm for females and 54.55 cm for males. The species spawns multiple times, with oocytes maturing in batches, being released at intervals. According to the results of this study, it was possible to notice that reproductive peaks occurred in February, May, and November. Therefore, it is recommended that the capture of this species be avoided during these months.

Keywords: biometrics; reproductive biology; fisheries planning.

Indicadores quantitativos da biologia reprodutiva de espécimes adultos de *Centropomus undecimalis* (Teleósteo: Centropomidae) obtidos de pescadores comerciais na Área de Proteção Ambiental do Delta do Parnaíba, costa norte do Brasil

RESUMO

Centropomus undecimalis (conhecido popularmente como robalo) é um recurso pesqueiro muito importante para a pesca comercial e recreativa. No presente estudo, objetivou-se avaliar indicadores quantitativos da biologia reprodutiva de *C. undecimalis* na Área de Proteção Ambiental do Delta do Parnaíba (Brasil). Os parâmetros foram analisados nos diferentes estágios do ciclo reprodutivo de 155 exemplares, sendo 135 (87,10%) machos e 20 (12,90%) fêmeas. Os resultados mostraram crescimento alométrico positivo para fêmeas e negativo para machos. A proporção sexual foi de 1:6,75 (fêmeas: machos). A primeira maturação (L50) estimada foi de 57,21 para fêmeas e 54,55 cm para machos. A desova da espécie é do tipo múltipla (ou parcelada), com ovócitos maturando em lotes, eliminados a intervalos. De acordo com os resultados deste estudo, foi possível perceber que os picos reprodutivos ocorreram em fevereiro, maio e novembro. Portanto, recomenda-se que a captura desta espécie seja evitada durante os referidos meses.

Palavras-chave: biometria biologia; reprodutiva; ordenamento pesqueiro.

INTRODUCTION

Brazil has one of the largest coastal zones on the planet, approximately 8,500 km long, of which 2,975 km are part of the Brazilian Amazon Coast (BAC), made up of the states of Amapá, Pará, and Maranhão (Pereira et al., 2009; Brasil, 2018). This region is one of the most important fishing centers in the country due to its high productivity (Stride et al., 1992; Lessa et al., 1999; Marceniuk et al., 2019; Coelho et al., 2021). The Maranhão coast accounts for 8.7% of the Brazilian coast and is the second largest in extension in all of Brazil. The state's coastline is 640 km long, second only to the coastline of the state of Bahia, which is 932 km long (IBGE, 2021). The wealth of aquatic organisms found in this region is invaluable, with a variety of fish and crustacean species important for commercialization, and this coast is one of the most diverse in Brazil (Silva et al., 2021).

The common snook of the species *Centropomus undecimalis* (Bloch, 1792) is a fish species of high commercial value caught by artisanal, industrial, and recreational fishing (Motta et al., 2016). In recent years, the demand for fish has been increasing, driven mainly by population growth and a global trend towards healthy foods. This demand has increased the capture of a larger number of fish, thus affecting the balance of populations (FAO, 2018).

In order to contain the decline of populations in natural environments, protection areas were established as one of the alternatives to enable environmental exploitation, ensuring the durability of renewable environmental resources and ecological processes (WWF, 2021). This is the case in the Tutóia region, located on the eastern coast of Maranhão, which belongs to the Parnaíba Delta Environmental Protection Area (EPA), a conservation unit established in 1996 (ICMBio, 2017), where fishing is an activity of great economic importance for the population.

The Environmental Protection Area of the Parnaíba Delta has an extension of 307,590.51 acres and is considered the only open sea delta in the Americas, located between the states of Maranhão and Piauí (Pinheiro et al., 2020). Because it is a Sustainable Use Conservation Unit, it allows the extraction of its resources (ICMBio, 2017). In this context, studies on the reproductive biology of fish are important because they allow environmental managers to create standards so that fishing resources can be extracted in an orderly manner (Nascimento et al., 2021) avoiding the depletion of stocks.

In Brazil, studies on the reproductive biology of sea bass have already been developed by Ferraz et al. (2013), in Santa Catarina, Costa-Filho and Mello (2015), in Ceará, and Farias et al. (2017), in Pernambuco. Nevertheless, in these states, the research was focused on captive breeding and dihybrid crosses. In the states of São Paulo and Pará, Silva et al. (2019) and Pereira et al. (2020), respectively, conducted studies on the reproductive biology of *C. undecimalis* through the ethnoknowledge of fishermen. In the state of Sergipe, a research study developed by Pinto et al. (2018), obtained allometric data similar to those obtained in this study. For Maranhão, this study is of great relevance because the state does not have a period established for sea bass and disordered catches can compromise its reproductive cycle.

C. undecimalis is found in marine and estuarine waters, and, to a lesser extent, in freshwater. The species uses these environments depending on the different phases of its life cycle (Cerqueira, 2005; Brame et al., 2014; Vieira, 2017). Thus, studies on the reproductive biology of fish provide relevant information for formulating fishing regulations, regarding the time, place, and capture size of individuals within a management program, providing necessary subsidies for rational exploration (King, 1995; Prestes et al., 2010; Cardoso et al., 2018). Thus, this study aimed to evaluate quantitative indicators of the reproductive biology of *C. undecimalis* in the Parnaíba Delta Environmental Protection Area (Brazil). Biometric data, sex ratio, first sexual maturity, reproductive peaks, and spawning types are highlighted for the recommendation of fishing planning and species conservation strategies.

METHODOLOGY

Area description

This study was carried out in the municipality of Tutóia, which is located in the Parnaíba Delta Environmental Protection Area (EPA), created in 1996, and which has an extension of 307,590.51 hectares and covers three states in the Northeast: Piauí, Maranhão, and Ceará (ICMBio, 2017). The city of Tutóia (2º45'44'' S; 42º16'28 '' W) is located in this EPA and has high fishing productivity. The relief is moderate, except for the coast where there are dunes (Figure 1). Due to its geographical location near the Equator Line, temperatures remain high throughout the year, ranging from 21 to 38°C. The climate supports a rainfall index of 87 mm with two characteristic seasons: the rainy season from January to June and the dry season from July to December, while the ENE winds have speeds of approximately 10 to 28 km/h (Climatempo, 2021). In addition, the tidal current speed in the region varies annually from 0.51 to 1.53 m/s (Galdino et al., 2018; Brasil, 2019).

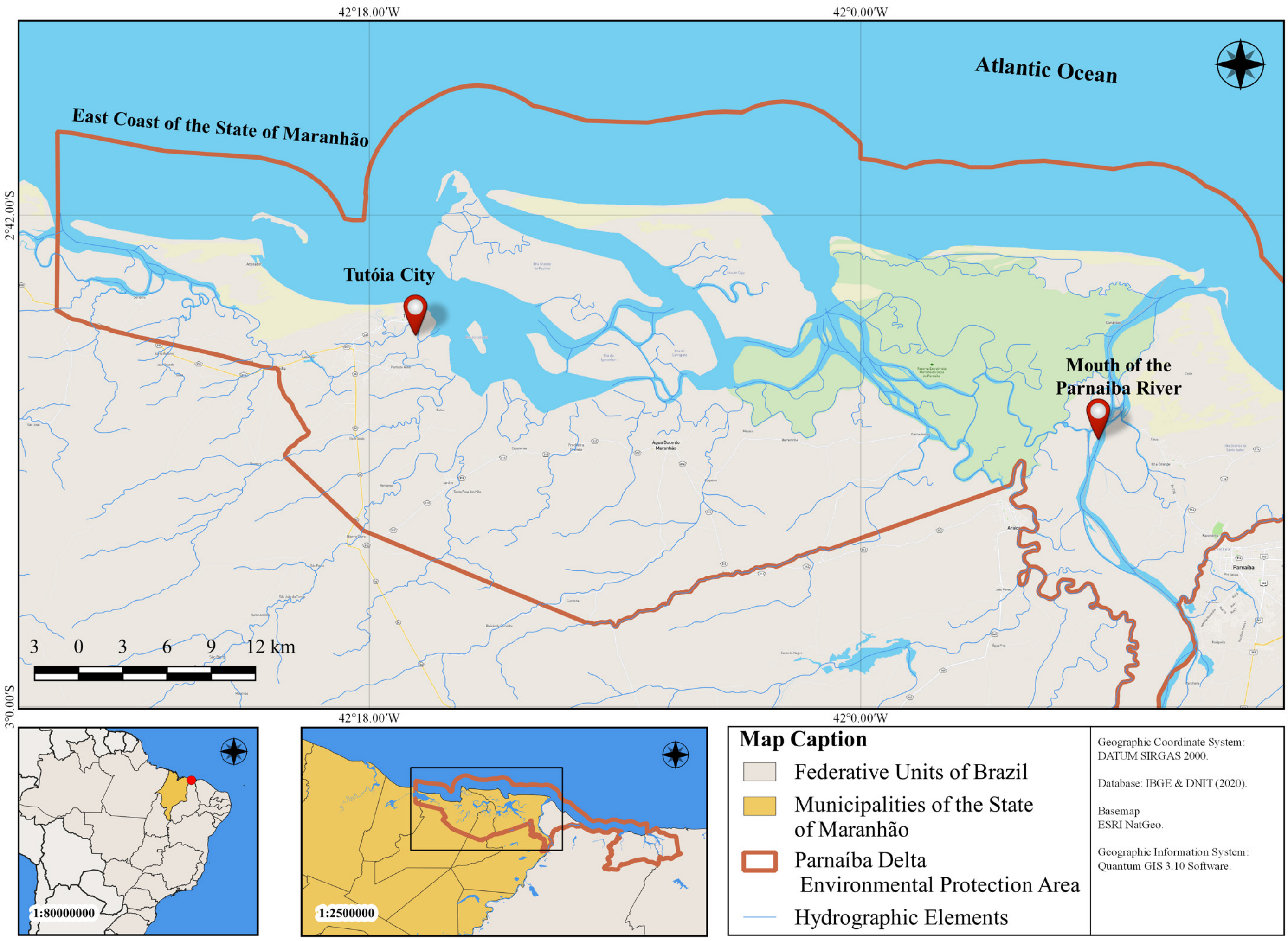
Ethics Committee

All methodological procedures for fish management were approved by the Ethics Committee of the Universidade Estadual do Maranhão (UEMA) (no. 4.476.902/2020). The common snook (*C. undecimalis*) were acquired monthly through commercial purchases in the city of Tutóia, Maranhão, from January 2019 to February 2020.

Laboratory analysis

The samples were analyzed at the Laboratory of Fisheries and Aquatic Ecology, UEMA, where they were previously identified. Total length (1 cm accuracy), total weight, gutted weight, gonad weight in grams (0.01 g accuracy), sex, and stage of sexual maturation were recorded. The stages of sexual maturation and sex were determined by macro and microscopic analyses adapted by Brown-Peterson et al. (2011).

In each individual, a ventro-longitudinal section was performed to remove the gonads for identification at the macroscopic level, taking into account some external characteristics such as color, vascularization, volume compared to the abdominal cavity, blood irrigation, visibility of oocytes,



Source: Costa (2022).

Figure 1. Map of the North Coast of Brazil. The red pin icons and lines indicate the city of Tutóia (where the capture and commercialization of common snook of the species *Centropomus undecimalis* occur) and the Environmental Protection Area of the Parnaíba Delta, with its demarcation.

and presence of sperm and its consistency. A previously established maturation scale was used to classify the gonads into the following categories:

- IS: immature stage;
- DS: developmental stage;
- SCS: spawning capacity stage;
- RS: regression stage;
- RGS: regeneration stage (Brown-Peterson et al., 2011).

Then, the total weight (TW) was recorded on a precision scale of 0.01g.

When the determination of the stages of sexual maturation at the macroscopic level was impracticable, the gonads underwent microscopic analysis, following the usual histological techniques, where they were fixed in Bouin's fixative, with inclusion in paraffin and staining with hematoxylin-eosin.

Data analysis

Data analyses were performed in statistical software SPSS v. 19 and Statistica 7.0, the free version, with a significance level of 5%. The sex ratio between males and females was calculated by Chi-square and Fisher's Exact Test concerning the ratio of 1:1. The analyses were performed by total period, by month of collection, by length classes, by collection period (dry and rainy seasons), and by the maturation stage of the specimens. The means of biometric indices per collection period were analyzed according to one-way ANOVA, respecting the assumptions of homogeneity of variances (Levene test) and data normality (Shapiro-Wilk test). To compare biometric means as a function of gender, we used the Student's t-test.

The total length x total weight allometric ratio was calculated according to Pearson's Linear Correlation. The equation of the line used was Equation 1:

$$y = B + aX \quad (1)$$

where the dependent variable (y) was represented by the total length, while the independent variable (X) was represented by the total weight. From this relationship, negative allometric growth was classified as B < 3; positive allometric growth as B > 3; and isometric growth as B = 3. Data on correlation residues for males and females were compared according to Student's t-test.

The type of spawning was defined by observing the frequency of oocytes in each diameter interval. The pattern found was compared with the gonadosomatic index, condition factor, and frequency of maturational stages (Cantanhêde et al., 2016) and classified as: synchronous in one group, synchronous in two groups, synchronous in more than two groups, or asynchronous (Vazzoler, 1996). For the analysis of the size of the first sexual maturation (L50), the maturation stages were grouped into immature (IS) and mature (DS+SCS+RS+RGS), following Vazzoler (1996) and Ortiz-Ordónez et al. (2007). The percentage of mature stages per length class was calculated and considered as a dependent variable (Y) and the total length as an independent variable (X). Subsequently, these values were adjusted to a logistic curve, according to the Equation 2:

$$P = 1/(1 + \exp[- r (TL - L50)]) \quad (2)$$

Where:
P = proportion of mature individuals;
r = slope of the curve;
TL = Total length;
L50 = average length of sexual maturity.

The reproductive period was defined based on the bimonthly frequency of maturity and the assessment of the values of the gonadosomatic index (ΔGSI) and the condition factor (ΔK). The means of the ΔGSI between the months of collection were compared through unilateral ANOVA, applying the post-techniques of Games Howell for unassumed variances and Tukey's test for assumed variances. The biometric data of each individual were calculated based on the following indexes (Equations 3, 4 and 5):

$$\text{gonadosomatic index } (GSI = Wg / Wt \times 100) \quad (3)$$

$$\text{hepatosomatic index } (HSI = Pf / Wt \times 100) \quad (4)$$

$$\text{viscerosomatic index } (VSI = Pv / Wt \times 100) \quad (5)$$

Where:
Wg = weight of the gonad;
Wt = total weight of the individual;
PC = Wt-Wg (length weight ratio).

Once the GSI, HSI, and VSI results were obtained, the average and the standard deviations were calculated, dividing the sum of each piece of data by the total number of samples, using the Statistica 7.0 software. These data were also obtained in relation to gender, season, and month.

The ΔK is the difference between the two models K 1 and K 2 (allometric condition factor indices), given according to the Equation 6:

$$K\,1 = Wt/LTb \text{ and } K\,2 = PC/LTb \quad (6)$$

Where:
K 1 = total condition factor;
K 2 = somatic condition factor;
Wt = total weight of the individual;
TL = total length of the individual;
b = angular coefficient of the weight/length ratio (WL);
WL = Wt - Wg, in which: Wg= weight of the gonad.

The determination of the periodicity of the reproductive process was based on the variation of the mean values of the gonadosomatic index and on the monthly frequency of maturation stages. For each specimen of adult male and female (development phase, spawning capacity phase, regression phase, and regeneration phase), the gonadosomatic index was calculated, defining the percentage represented by the gonad compared to the total weight of the animal, as an indication of variations in gonadal development throughout the year. The reproductive period was delimited by the highest ΔGSI values, which correspond to the difference between GSI1 and GSI2, obtained monthly for the male and female specimens (Silva et al., 2021).

RESULTS

The quantitative indicators of the reproductive biology of *C. undecimalis* in the Parnaíba Delta Environmental Protection Area (Brazil), analyzed at the different stages of the reproductive cycle of 155 specimens (87.10% males and 12.90% females), indicated a higher presence of males during the months of January, March, April, July, and August. As for the females, the highest number of catches occurred in February. There was no capture of specimens of both sexes in June and September. Table 1 shows a summary of biometric data and GSI, HSI, and VSI data obtained in the present study.

Table 2 presents a summary of the results for sex ratio, first sexual maturity, length classes, and weight-length ratio of *C. undecimalis* obtained in this research.

Regarding the seasonality of the region and the presence of the sexes, we noticed that there was no significant difference between the frequency of males and females for the dry and rainy seasons. There were a few more males in the rainy season, but these data were not statistically significant. Therefore, there was no predominance of sex in relation to seasonality.

Table 1. Analysis of the biometrics of common snook fish sampled in the municipality of Tutóia, state of Maranhão, according to sex.

Variable	Sex				p-value [(a)]
	♂		♀		
	Mean ± SD	**Min. – Max.**	**Mean ± SD**	**Min. – Max.**	
TL (cm)	66.39 ± 4.33	57.20 – 78.50	70.52 ± 7.83	57.50 – 81.70	0.016*
SL (cm)	54.65 ± 3.78	46.50 – 66.50	58.81 ± 5.25	49.00 – 67.00	0.002*
FL (cm)	61.18 ± 4.06	51.50 – 74.00	65.47 ± 6.35	53.00 – 75.50	0.008*
TW (kg)	2.63 ± 0.58	1.71 – 5.50	3.50 ± 1.40	1.74 – 6.36	0.012*
W liver (g)	15.30 ± 5.56	5.82 – 31.26	29.04 ± 17.93	7.54 – 64.38	0.003*
W viscera (g)	2.44 ± 0.55	1.28 – 5.30	3.09 ± 1.11	1.57 – 5.85	0.019*
W stomach (g)	24.62 ± 11.88	9.30 – 97.60	44.12 ± 29.39	15.34 – 107	0.008*
W gonad (g)	16.49 ± 7.60	0.60 – 38.05	62.65 ± 55.33	0.75 – 204.50	0.001*
GSI	0.63 ± 0.28	0.03 – 1.57	1.58 ± 1.14	0.04 – 3.93	0.001*
HSI	0.59 ± 0.18	0.29 – 1.10	0.79 ± 0.28	0.21 – 1.24	0.006*
VSI	0.09 ± 0.01	0.06 – 0.14	0.09 ± 0.01	0.07 – 0.10	0.050

[a]Student's t-Test; *significant difference, p < 0,05.
TL: Total Length; SL: Standard Length; FL: Furcal Length; TW: Total Weight; W: Weight; GSI: Gonadosomatic index; HSI: Hepatosomatic index; VSI: Viscerosomatic index.

Table 2. Summary of reproductive data of *C. undecimalis* captured in Tutóia, state of Maranhão.

Sex Ratio	The result was 1:6.75 i.e., 1 female for every 6.75 males, with a statistically significant difference in the proportion between genders (X^2 = 48.75; G. L. = 1; p = 0.000). **Confirming that males were generally predominant in this study**.
First Sexual Maturity (L50)	Females (♀) reached the first sexual maturity with L50 = 57.21cm and males (♂) with L50 = 54.55 cm.
Weight vs. Length Ratio	Females have positive allometric growth, with y = (0.781x10-7) x 4.12653, i.e. they grow more in weight than in length. Males have negative allometric growth, with y = 0.0000158 x 2.8629, i.e. they grow more in length than they in weight.
Length Classes	Length classes ranged from 57.50 to 78.50 cm for males (66.39 ± 4.33) and from 57.50 to 81.70 cm for females (70. 52 ± 7.83).
Reproductive Period	The months of reproduction were February, May, and November, when a larger number of females with eggs were found in our samples.
Seasonality	It is noticed that the months of reproduction have a relationship with the rainy season, although this species can spawn multiple times throughout the year.
Spawning Type	It was defined by observing the frequency of oocytes in each diameter interval. Histological analyses of gonads revealed the simultaneous occurrence of oocytes at different stages of development, indicating multiple spawning

Source: Nascimento et al. (2021).

Length/weight ratio

The total length/weight ratio was generally characterized by the Equation 7:

$$y = 0.00000134x3.45171 \quad (7)$$

The inclination (b) was greater than three, indicating positive allometric growth, in which the total weight increased at a greater rate than the total length (Figure 2A).

For males, this relationship was obtained with the Equation 8:

$$y = 0.0000158x2.8629 \quad (8)$$

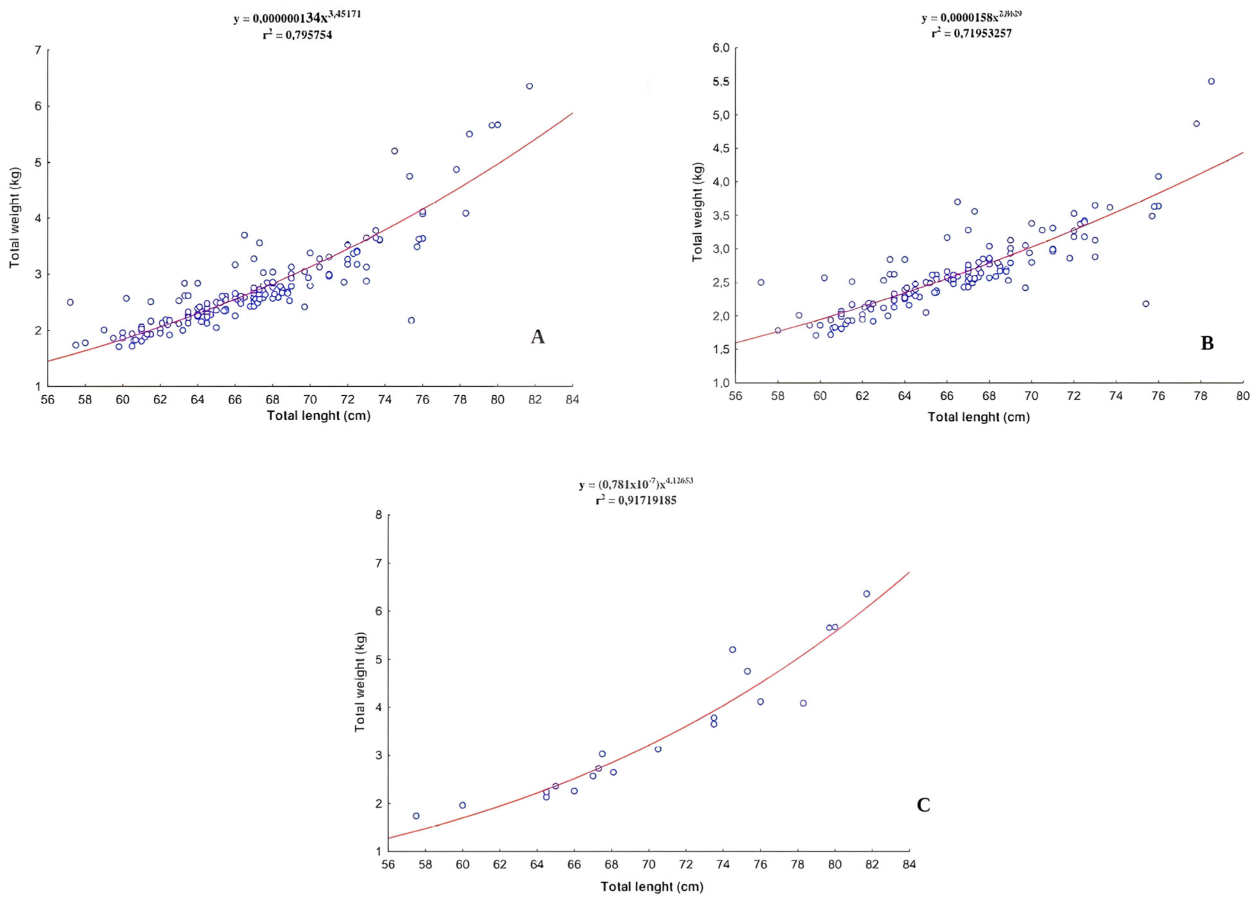


Figure 2. (A) Correlation between total weight and total length. **(B)** Correlation between total weight and total length for males. **(C)** Correlation between total weight and total length for females.

Presenting negative allometric growth, with a tendency to increase the total length compared to the total weight (Figure 2B).

Regarding females, the relationship was characterized by Equation 9:

$$y = (0.781x10\text{-}7)\ x\ 4.12653 \quad (9)$$

Where we observed positive allometric growth, with a tendency to increase the total weight compared to the total length (Figure 2C).

Macroscopic analysis of the gonads

All of the gonads removed were evaluated macroscopically. It was possible to observe four stages of gonadal maturation, with a predominance of the SCS for both sexes. The volume, color, thickness, and blood supply of the samples of ovaries of *C. undecimalis* varied according to the maturation stage. For the female samples, in the IS, the gonads showed a filiform aspect and pink coloration, without the presence of apparent oocytes and without signs of vascularization. In the DS, the ovaries were more developed, yellowish/orange in color, with oocytes becoming visible and turgid, but without evident signs of vascularization. In the SCS, the ovaries had an intense yellow coloration, with prominent oocytes and vascularization. In the final spawning or the RS, the fish gonads were usually hemorrhagic and flaccid, of intense red color. However, in this study, it was not possible to record any female specimens in the RS or RGS.

For the male specimens, the gonads in the IS were filiform and did not show apparent spermatocytes. In the DS, the male gonads were slightly more developed, with a pink coloration and slightly visible spermatic fluid. In the SCS, the gonads already capable of spawning showed a yellowish/whitish coloration with very evident spermatic fluid. In the RS, the gonads were flaccid and well vascularized, with the presence of some lateral fringes in some samples. The RGS was not observed in any of the male specimens.

Stages of maturation in the common snook

We found statistically significant differences among the maturation stages over the months of collection (Table 3). The last analysis indicated a higher frequency of individuals in the SCS for the month of February, a lower frequency of the DS for the month of July, and a higher frequency of the DS for the month of August.

Histological analysis

For microscopic analysis or gonadal histology, 32.26% of the total gonads were evaluated. Figure 3 shows a histological comparison of the gonads of *C. undecimalis* females. In Figure 3A, we can observe ovigerous lamellae filled with immature oocytes (IS). Figure 3B shows the presence of larger oocytes, with a slightly whitish center, which indicates the presence of young oocytes in the DS with a large number of initial and final perinuclear oocytes and cortico-alveolar oocytes. In Figure 3C, the presence of large oocytes, with lipid vitellogenesis in different phases, indicates the SCS maturation stage. In Figure 3D, it is possible to identify the presence of oocytes in “atresia”, a process resulting from the loss of cellular turgidity that leads to degeneration by rupture of the vitelline membrane. According to Vazzoler (1996), this type of follicle usually occurs in mature or emptied ovaries, where even at different stages of maturation, there are oocytes at different stages of development, which shows that the species can spawn multiple times.

First sexual maturity

To calculate the mean duration of the first sexual maturity, the following equation was generated (Equation 10):

$$y = 1/(1+\exp(-(0.284108)*(x-(54.9028)))) \quad (10)$$

Where L50 was 54.91 cm for the grouped sexes of the species (Figure 4).

Reproductive period (ΔGSI) and condition factor (ΔK)

Comparative analyses of the ΔGSI and ΔK charts indicate that there was a difference in terms of months only for ΔK, and there was no difference for ΔGSI (Figures 5 and 6).

During the reproductive period of *C. undecimalis*, we observed, however, a tendency towards peaks in February and May, as well as in November. The Post-Technique of ANOVA detected statistically significant differences for the month of October when compared to the months of January 2019 ($p = 0.004$), March 2019 ($p = 0.015$), April 2019 ($p = 0.019$), May 2019 ($p = 0.041$), July 2019 ($p = 0.019$), August 2019 ($p = 0.003$), and February 2020 ($p = 0.006$).

Thus, the month of October had the lowest average of ΔK compared to the other months mentioned. This may have happened because we did not have the presence of females and the “n” sample was small or because these samples were

Table 3. Frequency analysis of the maturation stage as a function of the months of collection of the common snook sampled in the municipality of Tutóia, state of Maranhão.

Months N (%)	Maturation stage				p-value
	IS (n = 14; 9.03%)	DS (n = 70; 45.16%)	SCS (n = 56; 36.13%)	RS (n = 15; 9.8%)	
Jan/2019	2 (15.38)	11 (84.62)	0 (0.0)	0 (0.00)	
Feb/2019	0 (0.0)	6 (24.00)	19 (76.00)	0 (0.0)	
Mar/2019	0 (0.0)	4 (30.77)	9 (69.23)	0 (0.0)	
Apr/2019	2 (11.11)	6 (33.33)	9 (50.00)	1 (5.56)	
May/2019	0 (0.0)	10 (66.67)	5 (33.33)	0 (0.0)	
Jun/2019	-	-	-	-	
Jul/2019	2 (20.00)	0 (0.0)	8 (80.00)	0 (0.0)	0.0009*
Aug/2019	0 (0.0)	13 (86.67)	2 (13.33)	0 (0.0)	
Sep/2019	-	-	-	-	
Oct/2019	3 (50.00)	3 (50.00)	0 (0.0)	0 (0.0)	
Nov/2019	3 (37.50)	5 (62.50)	0 (0.0)	0 (0.0)	
Dec/2019	0 (0.0)	3 (50.00)	0 (0.0)	3 (50.00)	
Feb/2020	0 (0.0)	8 (33.33)	10 (41.67)	6 (25.00)	

IS: immature stage; DS: development stage; SCS: spawning capacity stage; RS: regression stage; [a]Fisher’s exact test; *significant difference, $p < 0.05$

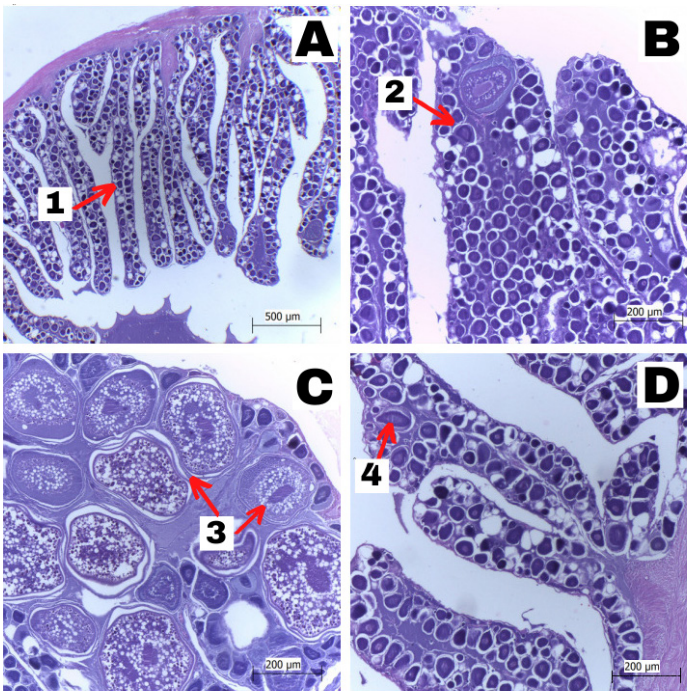


Figure 3. Gonadal histology of *Centropomus undecimalis* females. **(A)** Ovigerous lamellae with immature oocytes (1); **(B)** Oocytes at DS of maturation (2); **(C)** Mature oocytes with spawning capacity (3); **(D)** Atresic follicle (4).

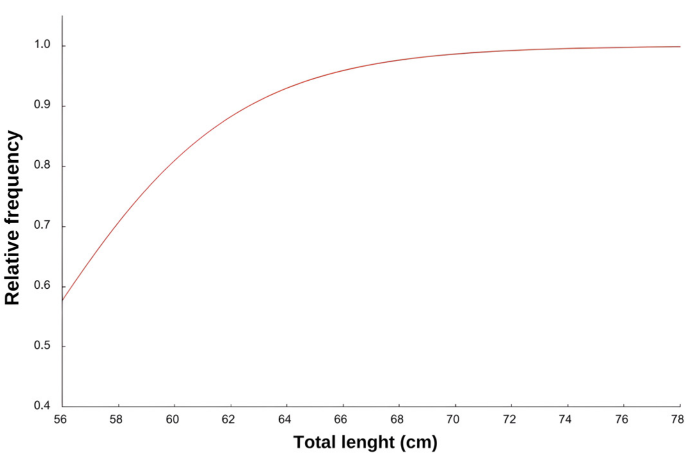


Figure 4. Estimated mean duration of the first sexual maturation (L50) of the common snook population.

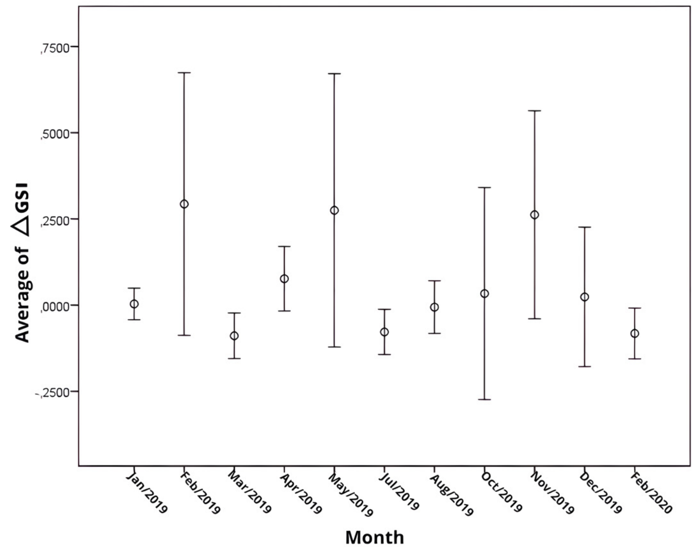


Figure 5. Comparison between the means of the ΔGSI in females per month of collection.

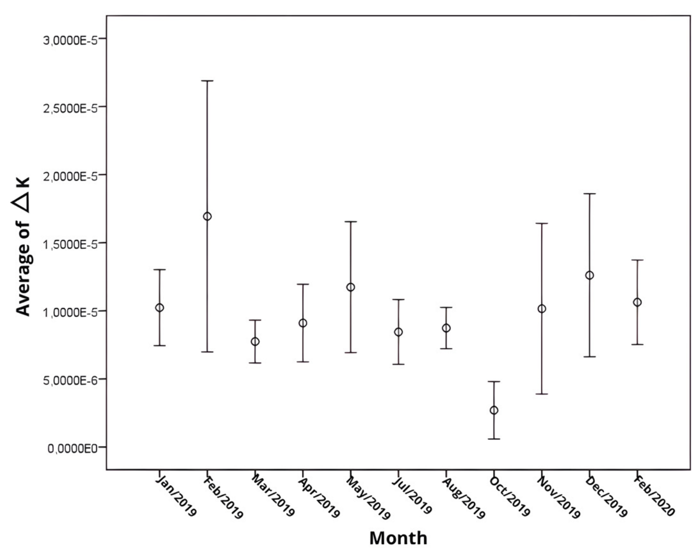


Figure 6. Comparison between the means of the ΔK per month of collection.

impacted by the oil spill that occurred in September 2019 on the Brazilian coast, which may even have reduced the number of captures.

Biometric data indexes

In the analysis of biometric indices, differences were observed among the months of collection, sex, and maturation stage (Table 4).

The mean GSI was significantly higher in females ($p = 0.001$) and in the SCS compared to the IS ($p = 0.000$) and the DS = ($p = 0.000$); however, there were no differences among the sampling months ($p > 0.05$). For the HSI, the highest averages were obtained in May/2019 compared to April/2019 ($p = 0.024$) and October/2019 ($p = 0.041$), as well as in females ($p = 0.006$); no significant differences were obtained for the maturation stage ($p > 0.05$). Concerning the VSI, February/2019 recorded a lower average compared to January/2019 ($p = 0.004$), March/2019 ($p = 0.000$), April/2019 ($p = 0.000$), May/2019 ($p = 0.004$), July/2019 ($p = 0.0003$), August/2019 ($p = 0.001$),

Table 4. Analysis of biometric indices of the common snook sampled in the city of Tutóia, Maranhão.

Variable	GSI	HSI	VSI
Period	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Dry	0.70 ± 0.56	0.63 ± 0.21	0.09 ± 0.003
Rainy	0.79 ± 0.58	0.60 ± 0.20	0.09 ± 0.01
p-value[(a)]	0.321	0.300	0.817
Months	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Jan/2019	0.75 ± 0.38	0.59 ± 0.19	0.09 ± 0.02
Feb/2019	1.06 ± 1.04	0.56 ± 0.27	0.08 ± 0.01
Mar/2019	0.59 ± 0.21	0.58 ± 0.16	0.10 ± 0.00
Apr/2019	0.70 ± 0.45	0.53 ± 0.19	0.10 ± 0.00
May/2019	0.89 ± 0.65	0.77 ± 0.19	0.09 ± 0.00
Jun/2019	-	-	-
Jul/2019	0.63 ± 0.29	0.74 ± 0.12	0.09 ± 0.00
Aug/2019	0.69 ± 0.20	0.61 ± 0.20	0.09 ± 0.00
Sep/2019	-	-	-
Oct/2019	0.20 ± 0.16	0.43 ± 0.08	0.09 ± 0.00
Nov/2019	0.71 ± 0.73	0.65 ± 0.25	0.09 ± 0.00
Dec/2019	1.02 ± 0.78	0.62 ± 0.24	0.09 ± 0.01
Feb/2020	0.83 ± 0.38	0.57 ± 0.10	0.10 ± 0.00
p-value[(a)]	0.09	0.002*	0.000*
Sex	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
♂	0.63 ± 0.28	0.59 ± 0.18	0.09 ± 0.01
♀	1.58 ± 1.14	0.79 ± 0.28	0.09 ± 0.01
p-value[(a)]	0.000*	0.000*	0.05
Maturation stage	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
IS	0.22 ± 0.19	0.65 ± 0.21	0.09 ± 0.01
DS	0.62 ± 0.28	0.58 ± 0.19	0.0943 ± 0.0068
SCS	1.08 ± 0.77	0.64 ± 0.24	0.0905 ± 0.0077
RS	0.66 ± 0.21	0.62 ± 0.15	0.09 ± 0.001
p-value[(a)]	0.000*	0.431	0.018*

IS: immature stage; DS: development stage; SCS: spawning capacity stage; RS: regression stage; SD: standard deviation; [a]one-way ANOVA test; *significant difference, $p < 0.05$; GSI: gonadosomatic index; HSI: hepatosomatic index; VSI: vicerosomatic index.

and November/2019 ($p = 0.015$) and February/2020 ($p = 0.001$). Also, there was a higher mean in individuals in the DS compared to the SCS ($p = 0.018$). There was no statistical relationship between sex and the VSI ($p > 0.05$). The results of this study show that the quantitative indicators of the reproductive biology of *C. undecimalis* in the Parnaíba Delta Environmental Protection Area are important to support the formulation of future strategies for fishing planning and conservation of this species.

DISCUSSION

The analysis of the length/weight ratio for separate sexes of *C. undecimalis* indicated negative allometric growth for males (growing more in length than in weight) and positive allometric growth for females, suggesting that females grow more in weight than in length. Martinelli (2010) also found similar data regarding the allometry of *C. undecimalis* in Ponta Negra, Natal, Rio Grande do Norte, and Gassman et al. (2017) found similar data in their studies with this species in Venezuela. The positive allometry of females can be attributed to the availability of food resources in the study environment, to the fact that females need more energy for reproduction, to the food ecology strategies of the common snook described by Nascimento et al. (2021) and Souza et al. (2021) in the Tutóia region, state of Maranhão, as well as to the fact that the study area is inserted in the Parnaíba Delta Environmental Protection Area (EPA), a sustainable use conservation unit administered by The Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), created by a decree (no number) of 08/28/1996, at the request of environmentalists to protect the coastal ecosystem formed by mangroves and dunes located in the states of Maranhão and Piauí (Brasil, 2002; Silva, 2018).

In terms of the sex ratio for the males and females of common snook (*C. undecimalis*), this research reveals a predominance of males of this species throughout the year. Studies by Caballero-Chávez (2011), Perera-García et al. (2011), Hernández et al. (2014), and Gassman et al. (2017) also reported similar data on the sex ratio of this species. These data have already been described in the literature, which may be associated with the fact that this species has a protandric hermaphroditic behavior, i.e. at a certain point in their reproductive biology, males undergo a modification of their gonadal structure and stop producing sperm, starting to produce female gametes.

Understanding the sexual pattern of a hermaphrodite species, such as the one presented here, is essential for an interpretation of its reproductive and ecological biology (Sadovy de Mitcheson and Liu, 2008). Furthermore, this understanding is necessary for the management of the species (Erisman et al., 2008) and the replacement of their population stocks. This study also observed that the sexual transition occurred outside the spawning season, since the female gonads found in the immature stage, when submitted to histological analysis, only had female gametes.

In addition, it is important to note that the sexual transition after a period of spawning has been documented in several species of hermaphrodite fish (Bentivegna and Berica Rasotto, 1983; Guiguen et al., 1994; Alonso-Fernandez et al., 2011). However, the probability of collecting individuals in a transition state is low (Bentivegna and Berica Rasotto, 1983; Villegas-Ríos et al., 2013), because this transition occurs rapidly, in less than a day for some species (Warner and Swearer, 1991). In this study, none of the samples collected presented gonads in transition.

Regarding the condition factor, the statistical tests showed a difference in ANOVA, and the statistical post-technique indicated October as the peak of the condition factor. If we take into account that the reports of fishermen reveal that there are periods of the year when the common snook disappears or is almost not caught, as we saw in September 2019, when this fish ran out, it can be a hypothesis that this temporary isolation may be a preparation for the peak of the condition factor. Usually, during the reproductive period of the species, the rates of the condition factor decrease due to the energy allocated for reproduction. Generally, reduced feeding during spawning contributes to weight loss or reduced growth. Gassman et al. (2017) described that the condition factor may vary monthly according to food availability, sex, seasonality, and gonadal degree of development.

Another environmental factor that may influence the decrease or "disappearance" of this fish in September/October may be the speed of winds in the region that become stronger during the summer and the scarcity of rains that can interfere with the fish distribution process. Also, these events of rainfall scarcity and higher incidence of winds in the Northeast may also occur alongside phenomena such as El Niño (which occurred in 2019) changing the temperature of the water environment (Silva, 2018) and influencing its dynamics.

According to Mendonça (2004), the reproductive period of *C. undecimalis* may interfere with the abundance of the species, that is, mature individuals from rivers and lakes may return to the sea to spawn (catadromous). After spawning, they remain for a season at sea and return to the estuarine environment soon after. Mature individuals (in the spawning phase), sampled in the present study, were predominant in both sexes.

Reproductive cycles represent the gonadal development necessary for mature fish to spawn at the appropriate time (Lowerre-Barbieri et al., 2011). In our study, we estimated the lengths of the first sexual maturity (L50; ♀ = 57.21 and ♂ = 54.55 cm), with males dominating the smallest sizes and females dominating the largest, a typical pattern seen among species with protandric hermaphroditism (Shapiro, 1984).

Over the reproductive period, this research describes that the months of February, May, and November were the ones with the highest incidence of females in the SCS. Caballero-Chávez (2011) identified the months of March to September as the reproductive season of *C. undecimalis*, with a peak in July in the southwest of Campeche; however, these results may have occurred differently due to the environmental conditions of each country, such as temperature variation, food availability, salinity, winds, and sea currents.

Regarding the maturation stages, IS, DS, and SCS were found for females and IS, DS, SCS, and RS for males. The RGS, however, was not found in any of the samples. Histological analyses confirmed the description of each oocytic stage, besides evidencing that they may contain different stages of oocyte development within the gonads, regardless of their maturation stage, which confirms that the species can spawn multiple times. The co-occurrence of different stages of oocytic development was similar to those described for *Centropomus parallelus* (Costa e Silva et al., 2021) and *C. pectinatus* (Daros et al., 2016; Freitas and Abilhoa, 2017). We also visualized follicles suffering atresia in the common snook samples we analyzed for this study. According to Vazzoler (1996), atretic follicles are those that may not have been eliminated for physiological reasons and, therefore, will end up undergoing degeneration, disintegration, and absorption. The author also points out that these atretic follicles are found in mature ovaries or in completely or partially emptied ovaries.

It is noticed that the reproductive behavior of many fish is cyclical, with a more or less regular period, in which the spawning period usually coincides with the favorable season so that young fish can grow and survive (Carvalho et al., 2021). Since external stimuli trigger hormonal adjustment that culminates in spawning, the environment should provide food in the necessary amount, protection against predators, favorable abiotic conditions, as well as conservation measures, from the anthropic point of view, that are adequate (Munro et al., 1990; Hilborn et al., 2020).

According to local fishermen, in the specific case of the populations of *C. undecimalis* on the coast of Maranhão, data are urgently needed, because the fishing fleet from other states such as Ceará, Piauí, Sergipe, and Pará is expanding, often with larger vessels than those of Maranhão, excessively and indiscriminately catching the fish resources of the Tutóia region. Meanwhile, management policies are still being formulated. If fishing is not managed in a manner that is consistent with the introduction of a closed season and greater protection of breeding sites, fishing will soon exceed the support capacity of the fish community (Cardoso et al., 2018).

Therefore, the data obtained in this study indicate, as a suggestion for fishing planning purposes, that common snook fishing (*C. undecimalis*) should be avoided in February, May, and November, when the probability of capturing females in spawning capacity is higher, consequently impacting the reproductive cycle of the species and its conservation.

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CONFLICT OF INTERESTS

The authors declare that they have no competing interests.

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AUTHORS' CONTRIBUTION

Nascimento, I.R.M.A.: Conceptualization, Methodology, Formal Analysis, Investigation, Writing — Original Draft, Project Administration, Funding Acquisition. Diniz, A.L.C.: Conceptualization, Methodology, Formal Analysis, Investigation, Writing — Original Draft, Project Administration, Funding Acquisition. Cruz, Y.L.K.F.: Design, Graphics, Writing — Original Draft. Azevedo, R.S.O.P.: Formal Analysis, Writing — Original Draft, Funding Acquisition. Azevedo, A.S.: Formal Analysis, Writing — Original Draft, Funding Acquisition. Pinheiro-Sousa, D.B.: Conceptualization, Methodology, Resources, Supervision, Writing — Original Draft, Funding acquisition. Sousa, D.B.: Conceptualization, Methodology, Resources, Supervision, Writing — Original Draft, Funding Acquisition. Carvalho-Neta, R.N.F.: Conceptualization, Methodology, Resources, Supervision, Writing — Original Draft, Funding Acquisition.

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