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Original Article

First sexual maturity and type of spawning of the fish *Conodon nobilis* (Linnaeus, 1758) from the Amazon coast – Brazil

Primeira maturidade sexual e tipo de desova do peixe *Conodon nobilis* (Linnaeus, 1758) da costa amazônica – Brasil

K. B. N. Queirós[a]*, N. B. Santos-Espínola[a], E. B. Ribeiro[b], R. N. F. Carvalho Neta[c], Z. S. Almeida[c+] and A. P. Costa[a]

[a]Universidade Estadual do Maranhão, Programa de Pós-Graduação em Ciência Animal – PPGC, São Luís, MA, Brasil
[b]Universidade Estadual do Maranhão, Programa de Pós-graduação em Biodiversidade e Biotecnologia – BIONORTE, São Luís, MA, Brasil
[c]Universidade Estadual do Maranhão, Departamento de Biologia, São Luís, MA, Brasil
[+]*In memoriam*

Abstract

The study of reproductive biology is an important tool in identifying protective measures to preserve fish stocks, providing essential data for a reliable management system that ensures a balance between the environment and the economy. This study aims to analyze the first sexual maturity and type of spawning of the fish *Conodon nobilis* (Linnaeus, 1758) on the Amazon coast, specifically in the Gulf Maranhense region. 360 specimens were obtained from commercial fishing activity in the community of Raposa-MA during the period from January to December 2021. Biometric data were recorded, and the gonadal maturation stages were determined through macro (maturation scale) and microscopic (histology) analyzes. Sex ratio, mean length of first sexual maturation and type of spawning were determined. Negative allometric growth was recorded for both sexes, indicating a greater increase in length than in weight, and the length varied from 11 to 31.8 cm and the sex ratio was 1 male:1.5 female. Individuals in all stages of maturation were observed throughout the year, with a predominance of individuals in spawning capacity and reproductive peaks in January, April and May, indicating that the species presents multiple spawning. The length at first sexual maturity (L_{50}) for females was 18.41 cm and for males was 18.91 cm. Knowledge of the mean size at sexual maturity can help define appropriate regulations for fishing, ensuring that individuals have the opportunity to reproduce at least once before being captured.

Keywords: reproductive cycle, conservation, reproductive dynamics, fisheries management.

Resumo

O estudo da biologia reprodutiva é uma abordagem importante na identificação de medidas de proteção para preservar os estoques pesqueiros, fornecendo dados essenciais para um sistema de gestão confiável que garanta o equilíbrio entre o meio ambiente e a economia. Neste estudo objetivou-se analisar a primeira maturidade sexual e o tipo de desova do peixe *Conodon nobilis* (Linnaeus, 1758) na costa amazônica, especificamente na região do Golfão Maranhense. Foram obtidos 360 exemplares provenientes da atividade de pesca comercial na comunidade pesqueira de Raposa-MA durante o período de janeiro a dezembro de 2021. Foram registrados dados biométricos e determinados os estágios de maturação gonadal por meio de análises macroscópicas (escala de maturação) e microscópicas (histologia). Foram determinados a razão sexual, a duração média da primeira maturação sexual e o tipo de desova. Foi registrado crescimento alométrico negativo para ambos os sexos, indicando maior aumento no comprimento do que no peso, sendo que o comprimento variou de 11 a 31.8 cm e a proporção sexual foi de 1 macho:1.5 fêmea. Foram observados indivíduos em todos os estágios de maturação durante todo o ano, com predomínio de indivíduos em capacidade reprodutiva e picos reprodutivos em janeiro, abril e maio, indicando que a espécie apresenta desovas múltiplas. O comprimento na primeira maturidade sexual (L50) para as fêmeas foi de 18.41 cm e para os machos foi de 18.91 cm. O conhecimento do tamanho médio na maturidade sexual pode ajudar a definir regulamentos apropriados para a pesca, garantindo que os indivíduos tenham a oportunidade de se reproduzir pelo menos uma vez antes de serem capturados.

Palavras-chave: ciclo reprodutivo, conservação, dinâmica reprodutiva, manejo da pesca.

*e-mail: andrea.costa@professor.uema.br
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1. Introduction

Conodon nobilis (Linaeus, 1758), belonging to the Haemulidae family, is popularly known as striped coró or jiquiri, it gained the name "snoring fish" due to the characteristic sound produced by the friction of its teeth, amplified by its swim bladder (Pombo et al., 2014; Silva et al., 2019). Inhabiting mainly rocky substrates, sandy coastal areas and shallow, muddy bottoms, this species is capable of reaching depths of up to 100 m, showing a preference for surf zones compared to estuaries, which are often used as nursery areas (Oliveira, 1974; Lopes et al., 2010).

Its distribution covers the Western Atlantic, from the east coast of North America to the entire Brazilian coast (Lopes et al., 2010; Marceniuk, 2020), with special emphasis on the Northeast Region of Brazil. Although not a main target of commercial fishing, this fish is incidentally caught in large quantities in various fishing gears along the Atlantic coast (Silva et al., 2013; Lira et al., 2019). This practice generates significant impacts on fish populations, especially due to the removal of a large number of young individuals, which can compromise the sustainability of fishing stocks. It is highlighted that *C. nobilis* plays a significant role in serving as a biotic agent for transport of organic matter between reef environments and adjacent areas, due to their limited dependence on rocky substrate and wide dietary variety (Silva et al., 2013; Lira, et. al., 2019; Santos et al., 2021).

Understanding the reproductive biology of *C. nobilis* is an important requirement to assess its conservation status and to propose effective management measures, such as implementing restrictions on fishing periods, in addition to the use of selective gear that minimizes the capture of immature individuals, considering that the indiscriminate capture of fish in juvenile stages can compromise the natural replacement of populations and, consequently, the sustainability of fishing stocks (King and McFarlane, 2003).

Therefore, this study aims to analyze the first sexual maturity and type of spawning of the fish *C. nobilis* from the Amazon Coast of Brazil, specifically in the Gulf of Maranhão region.

2. Materials and Methods

2.1. Study area

The municipality of Raposa is located in the Gulf of Maranhão, between the Bays of São Marcos and São José, in the Amazon Coastal Zone (Figure 1). The Maranhense Gulf region, characterized by estuaries and mangroves, located northwest of the state of Maranhão (Teixeira and Souza, 2009), is inserted in the Upaon-Açu/Miritiba/Alto-Preguiças Environmental Protection Area, which was created by the Decree No. 12,428 of June 5, 1992.

Raposa is a traditional fishing community, which depends on small-scale artisanal fishing, and is also a strategic point for the flow of production, allowing the mooring of several small and medium-sized vessels (Viana et al., 2015; Monteles et al., 2009).

2.2. Sampling of Conodon nobilis

To analyze the reproductive aspects of *C. nobilis*, 30 individuals were acquired monthly, from January to December 2021, resulting in a total of 360 specimens analyzed. These specimens were obtained through commercial fishing by local artisanal fishermen, who used as fishing gear: longline, trawl net and corral for their capture. The acquisition of biological material was authorized by the Maranhão State Department of the Environment (SEMA), under license number 2010060024.

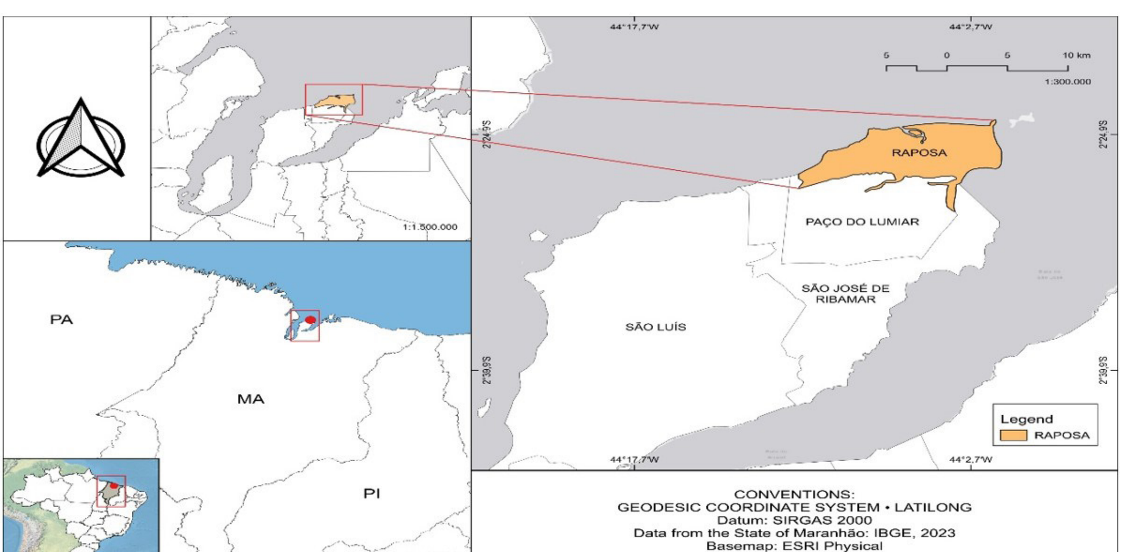


Figure 1. Study area; Municipality of Raposa -MA, Brazil.

The animals were stored in thermal boxes with ice and transported to the Zafira da Silva de Almeida Fisheries and Aquatic Ecology Laboratory at the State University of Maranhão for laboratory procedures. Biometric data of all specimens were recorded, such as total length (TL), standard length (SL) in centimeters, with the aid of a caliper. Total weight (TW) and eviscerated weight (EW) were recorded in grams, using a precision scale.

The weight-length relationship of males and females was established by the expression

$$TW = a \ x \ TL^b \quad (1)$$

where: TW represents the total weight, a is the linear regression coefficient, TL is the total length, and b is the angular regression coefficient, adjusted by the least squares method where a and b are parameters of the straight-line equation. The b coefficient was compared between males and females using Student's t test (Zar, 2010). The sex ratio was obtained for the total period, by month and by total length class. The χ^2 test (chi-square) with Yates correction (Snedecor and Cochram, 1974) was applied in order to evaluate possible differences in the sex ratio, considering the different classes of total length and per month.

2.3. Reproductive analyzes

The maturational stages and sex of the species were determined through macro and microscopic analyses. In each specimen, a ventro-longitudinal section was performed to extract the gonads and macroscopic identification, observing some characteristics such as: color, vascularization, volume in relation to the abdominal cavity, blood supply, visibility of oocytes, presence of sperm and their consistency. For the macroscopic classification of the gonads, a previously established maturation scale was used (Vazzoler, 1996), with terminology standardized by Brown-Peterson et al., (2011) and Lowerre-Barbieri et al., (2011), according to the following maturity stages: Immature phase (IM); Development phase (DP); Spawning capacity phase (SP); Regression phase (RP); Regeneration phase (RGP). The gonads were then weighed (GW) on a 0.01g precision scale. For microscopic analysis, the gonads were fixed in Bouin's solution for 24 hours. They were then dehydrated in an increasing series of alcohol (70%, 80%, 90%, 95% and two P.A alcohol baths), clarified in xylene and embedded in paraffin to obtain sections with a thickness of approximately 5 mm. The hematoxylin-eosin (HE) method was used for staining (Santos et al., 2021).

The reproductive period of *C. nobilis* was determined by analyzing the monthly frequency of maturity stages, the temporal variation of the average values of the gonadosomatic index (GSI) and the condition factor (ΔK), which is an indicator of the health status (healthiness) and can be expressed by the isometric or allometric condition factor (Le Cren, 1951). The gonadosomatic index was calculated for each individual, using the formula: GSI = (GW / TW) × 100, where GW = gonad weight; TW= total body weight.

For the analysis of the size at first maturation (L_{50}), the maturation stages were grouped into immature (IM) and mature (DP+SP+RP+RGP stages). The percentage of mature animals per length class was calculated and considered as the dependent variable (Y) and the total length as the independent variable (X). Subsequently these values were adjusted to a logistic curve using the Statistica 12.0 Program, according to the formula below: $P = 1/(1 + \exp[- r (TL - L_{50})])$, where P = proportion of mature individuals; r = slope of the curve; TL = Total length; L_{50} = average length of sexual maturity.

3. Results

3.1. Population structure

In the dry period (July to December) 103 females and 77 males were examined, while in the rainy period (January to June) 114 females and 66 males were analyzed. In total, 217 females and 143 males were evaluated, with male weights ranging from 68 g to 380 g and female weights ranging from 52 g to 560 g. The species had a total length varying between 17 and 29.4 cm for males and 11 to 31.8 cm for females. The frequency distribution of total length by sex revealed a greater number of females in all length classes ($P < 0.038$) (Table 1).

3.2. Sex ratio, frequency of maturation stages and reproductive period

The sex ratio, considering the total number of individuals, was favorable to females for *C. nobilis* (1M:1.5F) ($P < 0.029$). Considering the sampling period, females were more numerous in almost all collection months, but there was a significant difference only in the months of April and June. In the month of May, a higher number was observed for males ($P < 0.031$) (Table 2). The regression coefficient (b) found in the *C. nobilis* population demonstrated negative allometric growth for both sexes, indicating an increase in length rather than weight (Table 3).

Macroscopic evaluation of the ovaries revealed the presence of *C. nobilis* individuals at all maturation stages (Figure 2). The temporal frequency of the maturation stages of *C. nobilis* showed that the immature stage (IM) occurred in all collection months, with a higher proportion in February, June, October and November. Individuals in the developmental stage (DP) had a

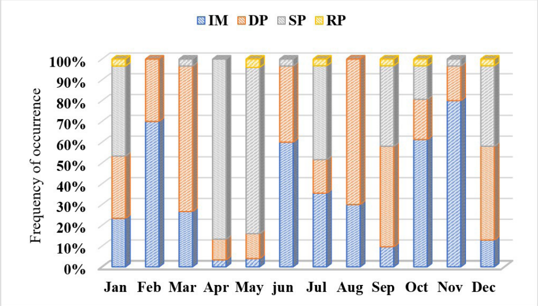


Figure 2. Frequency of occurrence of the maturational stages of *C.nobilis* from January to December 2021, municipality of Raposa-MA.

Table 1. Result of the Chi-square test, with Yates correction, for sex ratio by length class in *C. nobilis* in Raposa, between January and December 2021. * = significant difference (p< 0.05) by sex in length class during the sampled period

Length Class	F	M	Total	Fe	%Females	%Males	χ^2
10-12	1		1	0.5	100.00	0.00	1.00
14-16	1		1	0.5	100.00	0.00	1.00
16-18	18	13	31	15.5	58.06	41.94	0.81
18-20	56	27	83	41.5	67.47	32.53	10.13*
20-22	53	48	101	50.5	52.48	47.52	0.25
22-24	37	32	69	34.5	53.62	46.38	0.36
24-26	23	7	30	15	76.67	23.33	8.53*
26-28	18	6	24	12	75.00	25.00	6.00*
28-30	10	2	12	6	83.33	16.67	5.33
30-32	1		1	0.5	100.00	0.00	1.00
Total	217	143	360	180	60.28	39.72	15.21

Table 2. Result of the Chi-square test, with Yates correction, for monthly sex ratio in *C. nobilis* in Raposa, between January and December 2021. * = significant difference (p < 0.05) by sex in each month.

Months	F	M	% Female	%Male	χ^2
Jan	20	10	66.67	33.33	3.33*
Feb	17	13	56.67	43.33	0.53*
Mar	20	10	66.67	33.33	3.33*
Apr	23	7	76.67	23.33	8.53*
Mai	12	18	40.00	60.00	1.20*
Jun	22	8	73.33	26.67	6.53*
Jul	19	11	63.33	36.67	2.13*
Aug	19	11	63.33	36.67	2.13*
Sep	19	11	63.33	36.67	2.13*
Oct	17	13	56.67	43.33	0.53*
Nov	19	11	63.33	36.67	2.13*
Dec	10	20	33.33	66.67	3.33*
Total	**217**	**143**	60.28	39.72	15.21

Table 3. Regression equation for the relationship TL (cm) x TW (g) by sex and population of *C. nobilis*. R^2 = coefficient of determination. Constant "b" of the regressions for the relationship: Total length (mm) and Total weight (g) between sexes. b = angle of inclination of the straight line, t = Test t.

Sex	N	Regression equation	R^2	b	*t*	p
Males	143	$PT= 0.9386 \times Ct^{2.98}$	0.9386	2.98		
Females	217	$PT= 0.335 \times Ct^{2.75}$	0.94	2.75	0.827	0.495
Population	360	$PT= 0.0112 \times Ct^{2.82}$	0.9439	2.82		

higher occurrence in March, August, September and December, although they were found in all collections. A sharp margin of individuals with spawning capacity (SP) occurred in January, April, May, July, September and December, with a very significant occurrence in April and May, coinciding with the period of greatest rainfall for the region. For individuals in regression (RP), it was possible to observe small frequencies during all months, in relation to the other phases, being found in January, May, July, September, October and November.

The mean values of the gonadosomatic index (H=136.97, df=11, P = 0.0001) and the condition factor (H=143.54, df=11, P = 0.0001) coincided for the months sampled, which corresponds to January, April, May, July and September (Figures 3 and 4), showing statistical differences for females and males throughout the months.

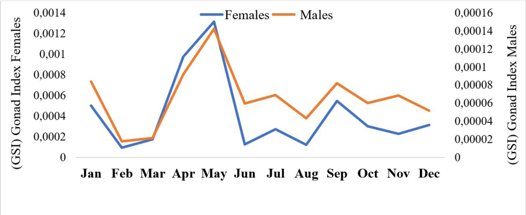


Figure 3. Mean values of the gonadosomatic index (GSI) for females and males of *Conodon nobilis* for the sampled period.

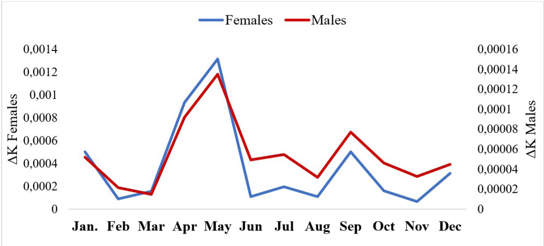


Figure 4. Mean values of condition factor (ΔK) of *Conodon nobilis* during the sampling period in Raposa, MA.

3.3. Macro and microscopic analyses of the ovaries

In the macroscopic analysis, five stages of ovary maturation were determined: Immature (IM), Developing (DP), Spawning Capable (SP), Regression (RP) and Regeneration (RGP) (Table 4).

The histological analysis of the female gonads allowed the following observations: the immature phase (IM) presents only primary growth oocytes (PG); there is little connective tissue between the follicles (Figure 5A). In the developing phase (DP), the ovaries present PG, cortical alveolar oocytes (CA), and also primary vitellogenic oocytes (Vtg1), with small yolk granules appearing first around the periphery (Figure 5B). No evidence of POFs or secondary and tertiary vitellogenic oocytes (Vtg3) at this stage. In the spawning capacity (SP) phase, secondary (Vtg2) and tertiary (Vtg3) vitellogenic oocytes are observed, the accumulation of yolk is basically complete and they present prominent blood vessels (Figure 5C). In the regression phase, it was possible to observe some post-ovulatory follicles (POFs), indicating the spawning of the species in the study area (Figure 5D).

The length at first sexual maturity (L_{50}) for the *C. nobilis* population was estimated at 18.92 cm. It was observed that females reach sexual maturity at slightly smaller sizes than males, at 18.41 cm and 18.91 cm, respectively, as demonstrated in Figure 6.

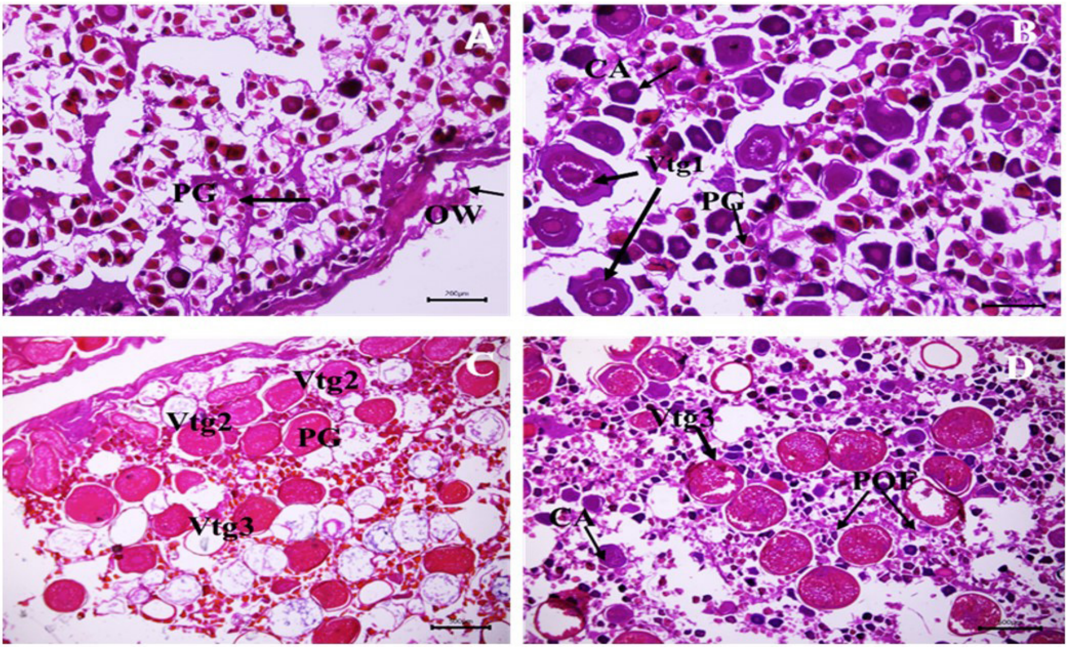
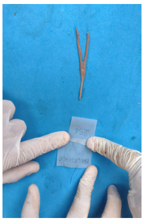


Figure 5. Histological sections of the *Conodon nobilis* ovary during the gonadal cycle. (5A) Immature ovary; (5B) Developing ovary; (5C) Ovary in spawning capacity; (5D) Ovary spawned/regression. PG: primary growth oocytes; OW: ovarian wall oocyte in phase II; CA: cortical alveolar oocytes; Vtg1: primary vitellogenic oocytes; Vtg2: secondary vitellogenic oocytes; Vtg3: vitellogenic oocytes; POFs: post-ovulatory follicles. HE 20x. Bar = 200 µm.

Table 4. Macroscopic identification of *Conodon nobilis* gonads.

Maturational stage	Macroscopic scale
 **Immature (IM)**	Filiform gonads, translucent, occupying up to 1/3 of the abdominal cavity thin ovarian wall, without muscle bundles, without oocytes to the naked eye.
 **Developing (DP)**	Enlargement of the ovaries, occupying 1/3 to 2/3 of the abdominal cavity, with more distinct blood vessels, simultaneous occurrence of several oocyte phases with the presence of some small, opaque oocytes.
 **Spawning capable (SP)**	Ovaries occupy practically the entire abdominal cavity, blood vessels prominent, oocytes visible macroscopically.
 **Regressing (RP)**	Flaccid ovaries, occupying 2/3 of the abdominal cavity, with blood vessels with a very hemorrhagic characteristic. Some oocytes can still be seen with the naked eye.
 **Regenerating (RGP)**	Sexually mature but reproductively inactive phase. The ovaries are small, blood vessels are small but evident.

4. Discussion

Conodon nobilis, in the Gulf of Maranhão, has a first sexual maturity length of 18.9 cm for grouped sexes, lower than that found on the coast of Alagoas for the same species (Silva et al., 2019), but greater than that recorded on the coast of Pernambuco (Lira et al., 2019). The average length at sexual maturity is important to define the minimum catch size, given the risk of overexploitation of fish stocks (Chellappa et al., 2010). This information is essential in fisheries science to guide management and conservation policies, often used globally to evaluate the capture of juveniles in fisheries (Viana et al., 2016; Lira et al., 2019).

Regarding the growth of *C. nobilis*, the results indicated negative allometry for both sexes. This pattern was similar to that found by Santos et al. (2021) on Maranhão Island, where the regression coefficient (b) was 2.67 ($b < 3$) for the

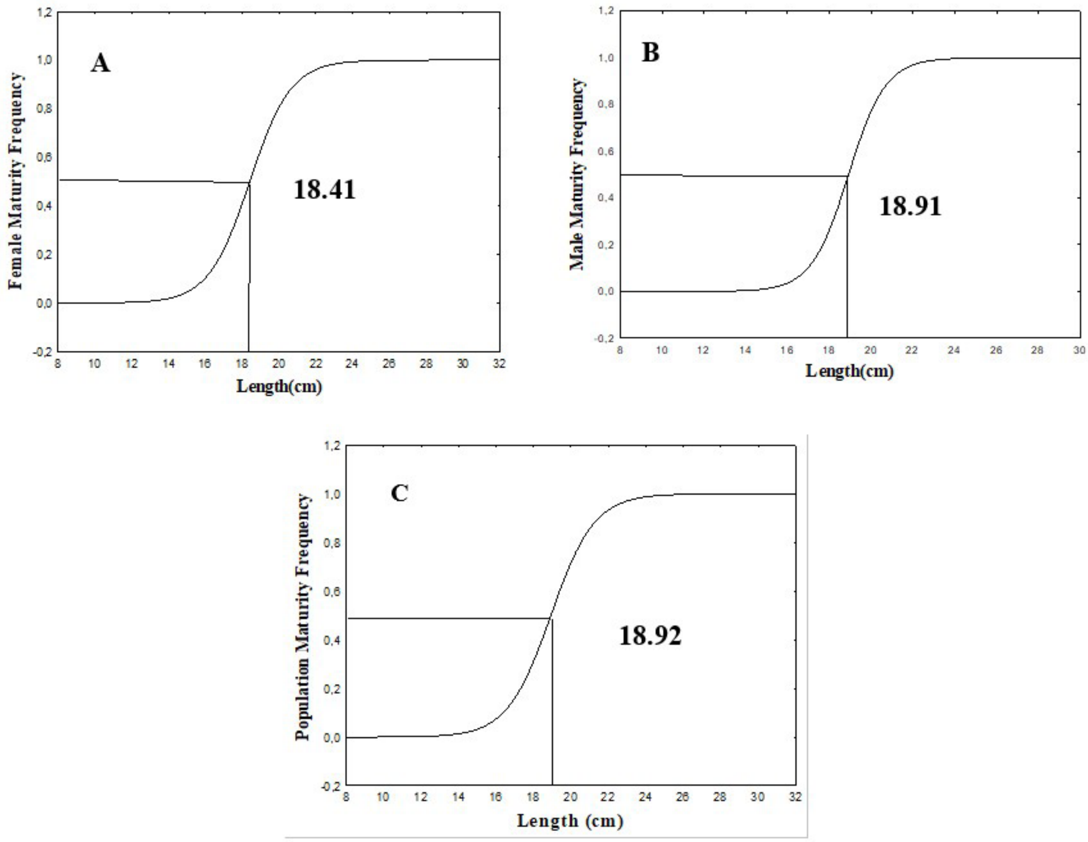


Figure 6. Mean values length at first maturation (L_{50}) for males and females of *C. nobilis*.

same species. This fact suggests that the energy acquired for this species is mainly directed towards investment in growth and not in weight gain.

In this study, the presence of females in the development (DP) and reproductive capacity (SP) phases was detected throughout the year, indicating that *C. nobilis* presents multiple spawning with group synchronized oocyte development in more than two batches. This pattern indicates a tendency to asynchronous, given the prolonged duration of reproductive periods, as already reported in the literature for other species (Isaac, 1988; Vazzoler et al., 1999). According to Cantanhede et al. (2016), this spawning method offers an advantage in situations of environmental impacts, as it provides the species with new reproduction opportunities.

The results showed that periods of greatest reproductive activity were marked by gonadosomatic peaks (IGS) and an increase in the condition factor (ΔK), which are parameters that reflect hormonal processes that regulate reproduction in fish, offering valuable information about the physiological state of these organisms (Vazzoler, 1996; Gomiero et al., 2010).The condition factor is an important metric in understanding the relationship between fish health and reproduction; it encompasses various aspects, including nutritional status, spawning readiness, reproductive effort, environmental influences, health, and disease (Shaner et al., 2023). Fish with higher condition factors tend to produce more and healthier eggs and sperm, leading to higher fertility rates and greater offspring survival (Chen et al., 2022).

Throughout the year, marked fluctuations in the values of these indices were observed, with higher peaks for both males and females occurring synchronously in January, April, May, July and September, mostly coinciding with the rainy season. Other research on the reproductive cycle with species of the Haemulidae family on the northeast coast of Brazil, showed a seasonal relationship with reproductive tendency of fish in the rainy season (Silva et al., 2013; Shinozaki-Mendes et al., 2013), demonstrating similarities with the data found here for *C. nobilis*. In research on ovarian development and spawning of fish belonging to other taxonomic families on the Northeast coast of Brazil, Chellappa et al. (2010), identified the rainy season as one of the environmental factors that influenced the occurrence of spawning of tropical fish (*Scomberomorus brasiliensis*). Similar results in terms of seasonality were also observed by Cantanhede et al. (2016) and Oliveira et al. (2012), indicating that the reproductive season may be influenced by local climatic conditions.

A significant prevalence of individuals in the immature stage (IM) was also observed, possibly from trawling, which captures many specimens accidentally, due to their low selectivity. According to what was described by Lira et al. (2019), *C. nobilis*, as it is a benthic carnivorous predator and feeds close to the bottom, has its population structure directly affected by trawling activity. These data are worrying, as they can have a potential impact on the structure of the marine food chain and the sustainability of fishing stocks (Oliveira et al., 2015), which could result in population imbalances. Such information can assist in the development of conservation measures for the species and in terms of public policies, such as the establishment of fishing ban periods for this species.

5. Conclusions

It was found that the majority of *C. nobilis* specimens reached first sexual maturity at 18.9 cm for combined sexes, exhibiting multiple spawning with more pronounced peaks during the rainy season. The data obtained from this research holds significant implications for the management and conservation of *C. nobilis* populations. Knowledge of the average size at sexual maturity can aid in establishing appropriate fishing regulations, ensuring that individuals have the opportunity to reproduce at least once before being captured. Additionally, understanding the pattern of spawning can influence the development of management strategies that take into account the species' reproductive periods, aiming to preserve stocks and ensure population sustainability.

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