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Reproductive pattern and population dynamics of *Anchovia surinamensis* in a seasonal floodplain lake of the Amazon basin*

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ABSTRACT

The Surinam anchovy (*Anchovia surinamensis*) is a small fish of commercial and ecological interest in the Amazon basin. To understand the reproductive and population dynamics of this species, in 2019 and 2020, experimental fisheries were carried out during periods of flood and low water in the Cujubim Lake in Porto Velho (Rondônia, Brazil). This study aimed to analyze the seasonal pattern (flood and low water) for the reproductive period and the population dynamics of the Surinam anchovy in this region, which resulted in the collection of 870 individuals. The specimens showed mean lengths (Ls) of 6.85 ± 0.51 cm to 9.01 ± 2.56 cm and mean weight (Wt) of 5.8 ± 3.37 g to 6.6 ± 2.72 g between low and flood water periods, respectively. The growth parameters for this species ($Wt = 0.0226*Ls^{2.6635}$; Natural mortality, M = 1.66 $year^{-1}$; Growth rate, k = 0.70 $year^{-1}$; Asymptotic length, L_∞ = 16.53 cm; Theoretical maximum weight, W_∞ = 42.83 g) and the quantity of individuals in mature stages during periods of flood and low water were also evaluated. The mean values of Gonadosomatic index - GSI (5.41 and 4.96 between females and males) and animal welfare index, *Kn* (1.009 and 1.010 between low and flood water periods) did not show significant differences. All the population growth information presented, added to the values of physicochemical parameters of the water (which were suitable for tropical fish) indicates that the Surinam anchovy population is governed by hydrological seasonality and is well adapted to the floodplain lake where it colonizes and reproduces.

Keywords: Engraulidae; gonadal maturation stage; length-weight ratio; population parameter; Surinam anchovy.

Padrão reprodutivo e dinâmica populacional da *Anchovia surinamensis* em um lago de várzea sazonal da bacia Amazônica

RESUMO

A sardinha-do-gato (*Anchovia surinamensis*) é um peixe de pequeno porte de interesse comercial e ecológico da bacia Amazônica. Para entender a dinâmica reprodutiva e populacional dessa espécie, foram realizadas pescarias experimentais nos períodos de seca e cheia nos anos de 2019 e 2020, no lago Cujubim in Porto Velho (Rondônia, Brasil). Este estudo teve como objetivo analisar o padrão sazonal (seca e cheia) para o período reprodutivo e a dinâmica populacional da *A. surinamensis* nessa região, que resultou na coleta de 870 indivíduos. Os exemplares exibiram medias de comprimentos (Cp) de 6,85 ± 0,51 cm a 9,01 ± 2,56 cm e peso (Pt) de 5,8 ± 3,37 g a 6,6 ± 2,72 g entre os períodos de seca e cheia, respectivamente. Os parâmetros de crescimento do estoque para esta espécie ($Pt = 0{,}0226*Cp^{2{,}6635}$; Mortalidade natural, M = 1,66 ano^{-1}; Taxa de crescimento, k = 0,70 ano^{-1}; Comprimento assintótico, L_∞= 16,53 cm; Peso máximo teórico, W_∞ = 42,83 g) e o quantitativo de indivíduos em estádios maduros durante os períodos de seca e cheia também foram avaliados. As médias dos valores do Índice gonadossomático - IGS (5,41 e 4,96 entre fêmeas e machos) e do Índice de bem-estar animal, *Kn* (1,009 e 1,010 entre a cheia e a seca), não apresentaram diferenças significativas. Portanto, todas as informações de crescimento populacional apresentadas, somadas aos valores dos parâmetros físico-químicos da água (que permaneceram adequados para peixes tropicais) indicam que a população da sardinha-do-gato é regida pela sazonalidade hidrológica e está bem adaptada ao lago de várzea onde colonizam e se reproduzem.

Palavras-chave: Engraulidae; estádio de maturação gonadal; relação peso-comprimento; parâmetro populacional; sardinha-do-gato.

INTRODUCTION

The Amazon basin is known for its vast flooded area that forms a complex water network, composed of rivers, streams, lakes, channels, and holes (Santos and Santos, 2005; Cella-Ribeiro, 2010; Albuquerque, 2015). This richness of aquatic environments is considered a nursery for the greatest biodiversity of freshwater ichthyofauna on the planet (Brito et al., 2019). In this region, river level variation (flood pulse) governs the composition and structuring of fish assemblages in flooded areas (Hurd et al., 2016). It also connects channels between rivers and lakes during the periods of flood water, which is the moment when the aquatic biota synchronizes its processes of reproductive dispersion and feeding (Garcez and Freitas, 2008; Hurd et al., 2016; Camargo, 2018).

In the Amazon basin, fish populations are hypothetically divided into two groups, those of commercial interest (Goulding et al., 2019) and those of ecological importance (Val, 2019). The latter has little economic value; however, it provides an environmental service that is fundamental for the maintenance and existence of the first group, since they act as base fish of the trophic chain (Barthem and Fabré, 2003; Albuquerque, 2015) and maintain the balance of the ecosystem that they occupy (Albuquerque, 2015).

In the group of foraging fish species, we find the family Engraulidae, which comprises 17 genera and 159 species worldwide (Fricke et al., 2020), of which nine are freshwater and occur in Brazil (Whitehead et al., 1988; Loeb, 2015), and in which the species known as sardines are inserted (Loeb and Menezes, 2015). These are fish that have diverse eating habits, but the planktophagous species predominate (Queiroz et al., 2013).

Among the species of sardines is *Anchovia surinamensis* (Bleeker, 1866), also known as the Surinam anchovy, a fish that is small (Steindachner, 1880), with lengths that range from 8 to 15 cm (Froese and Pauly, 2021). Its distribution is between Central and South America, and it can be found on the lower parts of the rivers of Trinidad and Tobago, to the east of Venezuela, and in the Brazilian part of the Amazon basin, where they breed. The highest breeding frequency is in the period from July to September when the tropical lakes are at their deepest (Talat et al., 1995; Queiroz et al., 2013), which indicates that these fish populations select the environments that have availability of food and breeding areas according to the seasonality of the river level (Tejerina-Garro and Mérona, 2010; Souza et al., 2015).

In this sense, studies that deal with the population structure and the reproductive seasonal frequency of *A. surinamensis* in the floodplain lakes of the Amazon basin were not found, only research related to taxonomic lists of catches, food items, and morphological comparison between the diverse groups of the family Engraulidae (Nelson, 1984; Bornbusch, 1988; Dario, 2009; Tejerina-Garro and Mérona, 2010; Loeb and Menezes, 2015; Orsi et al., 2018; Cavalcanti et al., 2019).

Understanding the population dynamics of a given fishery stock is crucial for its management (Beverton and Holt, 1957). However, knowing the seasonal pattern of rivers, their physicochemical parameters, and the state of preservation of the environment where fish populations reside are also important for a better understanding of the reproductive and behavioral processes of these animals (Melo et al., 2009). As such, the allometric condition factor (*Kn*) (Le Cren, 1951) is one of the factors used to observe the well-being of a species in relation to the environment in which it lives (Le Cren, 1951). It is known that more than one environmental factor can influence the reproductive process of fish (Barbieri, 1995) and, in addition to the hydrological cycle, there is a combination of environmental stimuli that help fish populations find conditions to maximize reproductive success (Bromage et al., 2001).

Water quality presents the physicochemical characteristics that can alter the growth, reproduction, behavior, and frequency of organisms (Rangel-Serpa and Torres, 2015; Lima et al., 2017). For this reason, the parameters of water are frequently evaluated to establish environmental quality standards and their interactions with the dynamics of the fish populations (Coimbra et al., 2017; Sousa et al., 2020).

Studies related to the reproductive pattern and dynamics of *A. surinamensis* populations appear to be necessary since this species is the basis of the diet of larger fish-eating species, such as large migratory catfish, which are targets of commercial fisheries in the Amazon (Winemiller and Jepsen, 1998). Thus, the present study aimed to analyze the seasonal pattern (flood and low water) for the reproductive cycle and basic data on the population dynamics of the Surinam anchovy in the Cujubim Lake, in the state of Rondônia, Brazil.

Given that the seasonal patterns of the Amazonian rivers interfere in the population and reproductive dynamics of fish assemblages (Winemiller and Jepsen, 1998), in this study we sought to verify whether the flood pulse and the environmental parameters of Lake Cujubim interfere in the reproductive and population dynamics of *A. surinamensis* that inhabit the lake. As such, our hypothesis was that there are no seasonal differences for the variables presented above, which was tested herein. The results shown here aim to subsidize information that may assist in the base for future studies of the species in Amazonian floodplain lakes.

MATERIALS AND METHODS

Study area

The data were collected in the Cujubim Lake, which has an approximate area of 2,195.26 ha (Figure 1) and is located in an extensive lowland area (8º36´14"S, 63º40´44"W) that connects to the right bank of the Madeira River during the flood period, but loses this connection with the river during the low water period.

Data collection

The experimental fisheries were carried out in the periods of flood and low water in 2019 (March and October) and 2020 (February and October), totaling one month in the flood period and one month in the low water period in each year. Specimens of *A. surinamensis* were captured using three batteries of monofilament nylon nets (2 m high by 20 m long), with mesh sizes of 40, 60, 80 and 100 mm (mounted side-by-side). We also used a drift net (with the same measurements as the fixed nets), as well as a cast net (8 cm between opposite knots, 0.50 thread, and 20 m spread, with a height of 2.50 m). The nets were arranged

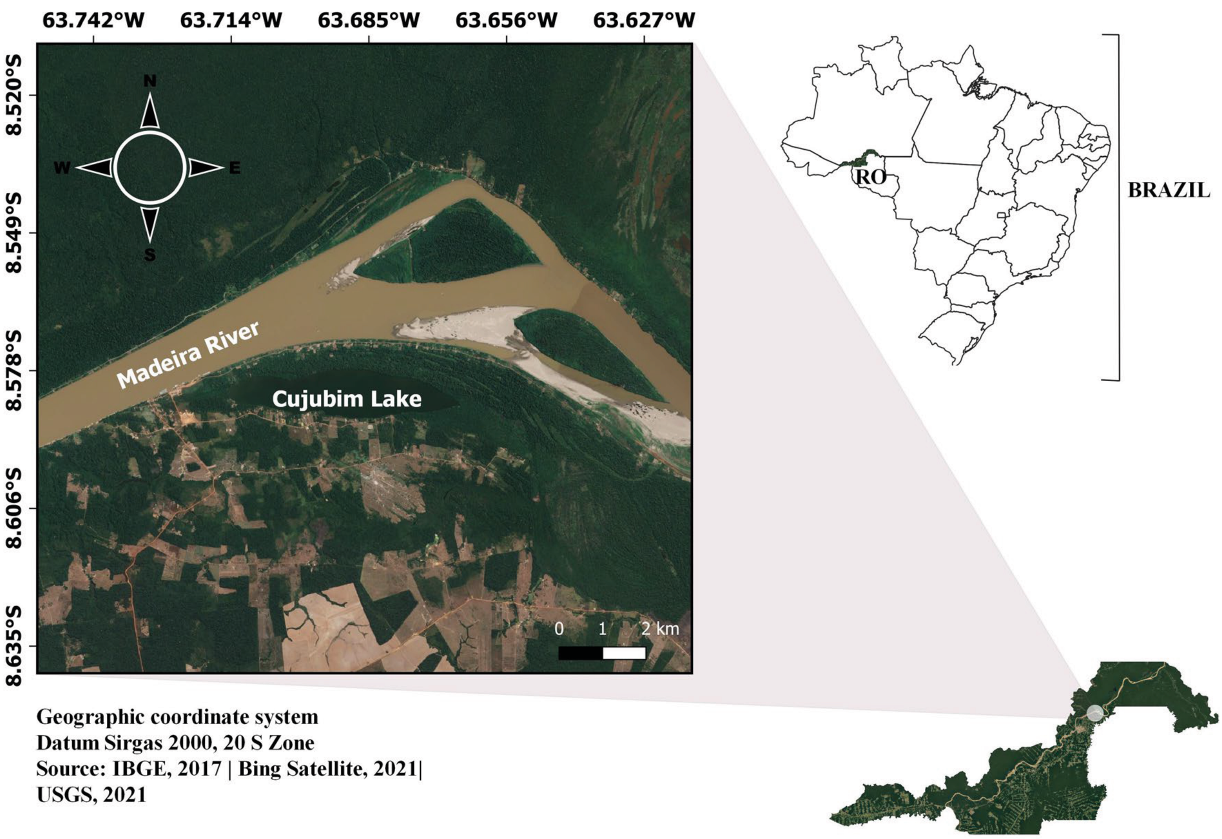

Figure 1. Location of the Cujubim Lake in the Madeira River basin (Rondônia, Brazil).

in pre-established positions near the shores and in the central part of the lake, and inspections were carried out at 06:00 p.m., 12:00 p.m., 06:00 a.m. and 12:00 a.m. (over two days).

After collection, each individual was euthanized by spinal cord section (CFMV, 2012), followed by biometrics to measure standard length (0.1 cm) and total weight (0.01 g). The experimental fisheries were authorized by the Chico Mendes Institute-ICMBio under license number 66945-2, and the research project was approved by the Ethics Committee for Animal Use (CEUA) of the Federal University of Rondônia, under registration 018/2019.

Subsequently, the fish were conserved in 10% formalin, labeled, and transported to the laboratory. Macroscopic analyses were carried out to obtain confirmation of the maturational stages of the ovaries and testes according to the scale proposed by Vazzoler (1996) and gender, as described by Brown-Peterson et al. (2011) and Lowerre-Barbieri et al. (2011). In each of the fish, we made an incision in the ventral portion, and the gonads removed, cleaned, weighed, and kept in a 25 mL glass bottle with formalin buffered at 10% and later in alcohol 70% for additional observations (Santos and Heid, 1981).

The size, shape, presence of blood vessels, presence of visible oocytes, stiffness and the proportion occupied in the abdominal cavity were observed in each gonad, according to the protocol of Honji et al. (2006). Furthermore, the macroscopic phase of the development of the ovaries and testicles was observed. The macroscopic identification of the gonadal maturation stages of females and males was carried out according to the scale proposed by Vazzoler (1996), where four phases were considered (immature or virgin, maturing, mature and empty).

For the seasonal analysis of the hydrological level of the Madeira River, two hydrological periods were considered, low water and flood. These were determined according to Cella-Ribeiro (2010), which defines the period of low water as any value below 950 cm (low water period – June to December). For the flood period, levels above 950 cm were considered, representing the period of January to May.

Concurrent with the experimental fisheries, water collections were performed in triplicate in nine locations along the lake (to achieve greater representativeness of the surface area of the lake) with the aid of a multiparameter probe (AKSO, model 8603). The methodologies used are in accordance with the Standard Methods for Examination of Water and Wastewater (APHA, 2017), which are used to evaluate pH, turbidity, electrical conductivity, alkalinity, and transparency (cm; measured with a Secchi disk). The water analyses were used to evaluate the health and level of conservation of the lake where the Surinam anchovy resides.

Data analysis

Length-weight ratios were estimated considering periods of flood and low water, with both sexes combined, and also separated into female and male sexes. The equation used was $Wt = a * Ls^b$, where Wt = total weight (g); Ls = Standard length; a and b = regression parameters characterizing the length-weight ratio (Froese, 2006). Pearson tests were performed to evaluate the significance of correlation coefficients (r). Analysis of covariance (ANCOVA) was used to compare the slopes of length-weight relationships between periods and sexes.

Allometry coefficient (b) values were analyzed and were considered isometric if b = 3; negative allometry if b < 3 and positive allometry if b > 3. The relative condition factor (Kn) was calculated using the equation $Kn = \frac{Wt}{We}$, as proposed by Le Cren (1951), where Wt = total weight (g) and We is the average weight estimated for each length by the equation $We = a \times Ls^b$, where a and b are the parameters of the length-weight ratio. The gonadosomatic index (GSI) was calculated by means of the equation $GSI = \frac{Wg}{Wt}$, where Wg = weight of the gonad (g) and Wt = total weight (g) (Vazzoler, 1996). The GSI of *A. surinamensis*, for males and females, was analyzed considering only the stages of gonadal maturation in reproduction phases, since immature fish were not obtained. The Student's t-test was used to verify whether there was a difference between the b value compared to the isometry value (3), the Kn (periods and sexes) and the GSI (sexes). All analyses were performed using the R 4.1.2 program (R Core Team, 2021).

The length data were used to estimate the parameters of the growth equation proposed by von Bertalanffy; $L_t = L\infty\left[1 - e^{-k(t-t_0)}\right]$, where L_t = fish length at age t; t = age; L_∞ = asymptotic length; k = growth constant and t_0 = theoretical age with zero length (King, 1995). The parameters L_∞ and k were estimated using the ELEFAN I routine contained in the FISAT software (Gayanilo Junior et al., 2005). Longevity ($A_{0.95}$), defined as the time it takes an individual to reach 95% of its asymptotic length, was estimated based on the formula proposed by Taylor (1958): $A_{0,95} = \frac{t_0 + 2{,}996}{k}$. The parameter t_0 was considered zero due to the initial size of the individual being negligible and because this parameter has no biological relevance.

The length at first sexual maturity (L_m) was given by the equation $\log (L_m) = 0.9469 \times \log (L_\infty) - 0.1162$ (Froese and Binohlan, 2000). The total maturation length (L_{100}) was also estimated according to the equation proposed by Froese and Binohlan (2000), namely: $L_{100} = L_m + (L_\infty - L_m)/4$.

Natural mortality (M) was estimated using the Pauly (1980) method, which relates natural mortality in fish to water temperature as a function of growth in length by means of an equation obtained by multiple regression: $logM = -0.0066 - 0.279 \times log\ L\infty + 0.6543 \times log\ k + 0.4634 \times log\ T$, where L_∞ and k = von Bertalanffy growth parameters and T = average annual water temperature in degrees Celsius (30.2°C).

The asymptotic maximum weight (W_∞) was estimated according to the equation below (Sparre and Venema, 1997): $W_\infty + a \times L_\infty{}^b$, where L_∞: = theoretical maximum length; a and b: = parameters of the length-weight ratio. Additionally, the values of W_∞, L_∞ and k were applied in the growth performance index – GPI ($Ø = log\ k + 2/3\ log\ W_\infty$ and $Ø' = log\ k + 2\ log\ L_\infty$) using ELEFAN I routine from FISAT software (Gayanilo Junior et al., 2005). The GPI permitted an evaluation between the growth parameters derived for *A. surinamensis* in the Cujubin Lake and the parameters for another anchovy that were available (Froese and Pauly, 2021).

RESULTS

A total of 870 specimens of *A. surinamensis* were captured and their lengths and weights measured. Sexes were significantly different between the periods (*ANCOVA*; $p < 0.01$) (Figure 2A). In the periods of flood water (N = 336) and low water (n = 531), the correlation coefficients (r) of 0.94 and 0.91, respectively, were significant (flood water: $t = 50.88$, $p < 0.01$); (low water: $t = 51.70$, $p < 0.01$). In the analysis that considered the sexes of

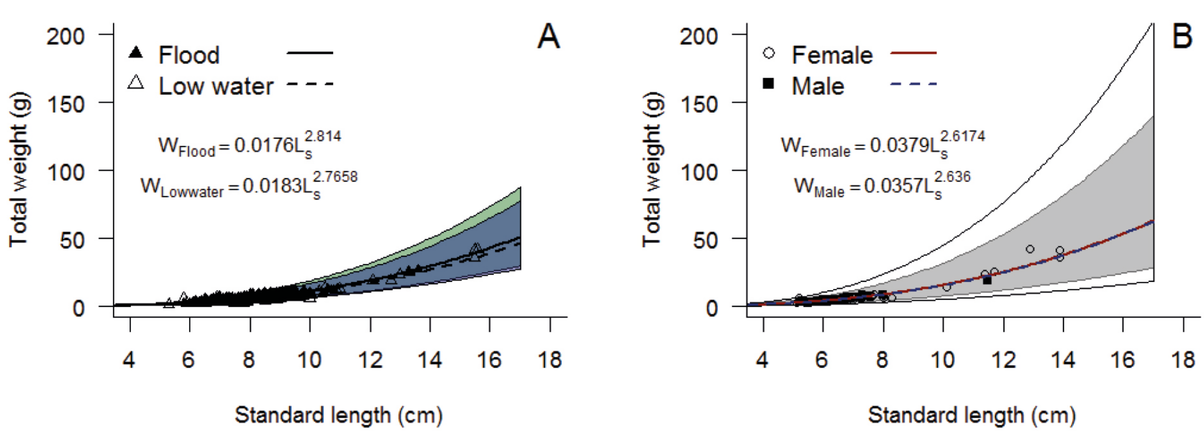

Figure 2. Length-weight relationships for the population of *Anchovia surinamensis* in flood and low water periods (A), and for females and males (B) in the Cujubim Lake, Rondônia, Brazil. Green (flood), blue (low water); gray (female) and white (male) polygons correspond to the confidence intervals of 95% of relationships.

the fish, 71 females and 34 males were used, and there was a significant difference between the slopes (*ANCOVA*; $p < 0.01$) (Figure 2B). The r values of 0.97 and 0.96 were significant for females ($t = 31.17$, $p < 0.01$) and males ($t = 20.73$, $p < 0.01$), respectively. The value of parameter b, verified by means of Student's t-test, was significantly less than 3.0 for both the flood water ($t = 15.16$; $p = 0.04$) and the low water ($t = 50.28$; $p = 0.01$) periods, and assume negative allometric growth (b<3).

Estimates of the relative condition factor (*Kn*) showed no significant differences ($t = –0.172$, $p = 0.86$) between periods of flood and low water, which had averages of 1,009 and 1,010, respectively. No significant differences also occurred between sexes ($t = –0.213$, $p = 0.83$) with averages of 1,012 and 1,006 for females and males, respectively.

In the 105 specimens analyzed (71 females and 34 males), the three of the stages proposed by Vazzoler (1996) were identified in the gonadal maturation and reproductive period of the Surinam anchovy. In the low water period, males (*Ls* ranging from 7.20 to 12.70 cm; 8.39 ± 1.51 cm) and females (*Ls* ranging from 6.40 to 15.60 cm; 9.01 ± 2.56 cm) were found in maturing and mature stages. In the flood period, female (*Ls* ranging from 5.80 to 8.30 cm; 7.21 ± 0.55 cm) and males (*Ls* ranging from 6.10 to 7.80 cm; 6.85 ± 0.51 cm) sardines were dominant in the stages classified as mature and empty, respectively. The gonadosomatic index (GSI) showed no significant differences between females and males ($t = 1.046$, $df = 77.859$, $p = 0.299$), with means estimated at 5.41 and 4.96, respectively.

The estimated population parameters showed that *A. surinamensis* presents growth ($k = 0.70$) and sexual maturation above 10 cm. However, the mean length of the individuals classified as mature or emptied was 7.8 cm. The population and reproductive data of the studied species were estimated for the natural population of the lake, considering only the biotic and abiotic parameters of occurrence at the study site (Table 1).

Water quality monitoring

Of the limnological parameters evaluated, only total alkalinity and temperature did not show significant differences between the means (t =1; p = 0.17 and 0.57, respectively). The other physicochemical parameters of the water presented significant differences (p <0.05) when comparing the analyses between the flood and low water period (Table 2).

DISCUSSION

The estimated intercepts (a) for *A. surinamensis* in the two periods and relating to sex were within the expected range between 0.001 and 0.05 (Froese, 2006), and the allometric coefficients (b) were negative and in the expected range between 2.5 and 3.5 (Carlander, 1969). Negative allometry that considered both aggregate periods was also verified for the Surinam anchovy population in the Cujubim Lake (Lima and Sousa, 2020). Negative b values denote that larger specimens changed their body shape and became more elongated, or the fish size classes were in better nutritional condition at the time of sampling (Froese, 2006). The first alternative could be verified by considering estimates of length-weight relationships between the classes of lengths, but individuals larger than 10.0 cm were

Table 1. Summary of population data acquired for *Anchovia surinamensis* from the Cujubim Lake, Rondônia (Brazil).

Population and reproductive parameters	Value
Average length (L_{mean}, cm)	7.93
Asymptotic length (L_{∞}, cm)	16.80
Average length at first maturation (L_{50}) (cm)	10.4
Maximum length at first maturation (L_{100}) (cm)	11.9
Theoretical maximum weight (W_{∞}, g)	48.20
Growth rate (k year^{-1})	0.70
Longevity ($A_{0.95}$) yea^{r} -1	4.28
Natural mortality (M year^{-1})	1.66
Growth performance index (φ)	2.29

Table 2. Means of the physicochemical parameters of the water evaluated in the Cujubim Lake, considering low and flood periods.

Environmental parameters	Low water	Flood	t-test
Dissolved oxygen (mg L^{-1})	7.4±0,71	1.2±0,50	*
Electrical conductivity (µS cm^{-1})	39.6±0,51	30.9±4,60	*
Turbidity (uT)	5.6±1,89	13.1±6,96	*
pH	7.9±0,58	6.1±0,07	*
Total alkalinity (mg L^{-1} $CaCO_3$)	8.4±1,33	8.0±0,0	0.17
Ammoniacal nitrogen (mg L^{-1} NH_3)	1.1±0,10	0.5±0,36	*
Temperature (°C)	30.05±0.71	30.87±0.77	0.57
Transparency (cm)	40.55±5.80	66.11±11.08	*

* Presented significant differences between the means with p <0.05.

reduced in number for both periods and sexes, which makes it possible to affirm that there is a tendency that small fish would have shifted the *b* to negative values. Additionally, parameter *b* can also vary because of seasons, locations, and years, resulting in different length-weight ratios (Froese, 2006), which also directly interfere with the relative condition factor values (*Kn*).

A. surinamensis in Baía do Marajó (located in the Pará State, Brazil), for example, presented positive allometry (3.01), but the amplitude of lengths (2.9 – 9.1 cm) was distinct in this work, and positive trend were also identified in 15 species of genus similar to that of *Anchovia*, out of 17 for which there are length-weight ratio estimates (Froese and Pauly, 2021). Therefore, in addition to the comparison of length classes, studies on feeding are necessary for a greater understanding of the phenomenon, since the flood cycle in floodplain lakes can affect young individuals who change diets frequently during the first year of life because of the quality and quantity of food available in the habitat (Fuiman and Werner, 2002). In the present study, the estimate of *b* was significantly negative in the low water period and may be an indication of scarcer or lower quality food supply. Between the sexes, differences in the slopes were less pronounced and inaccuracies in the estimates were greater, especially for male individuals.

However, when considering the relative condition factor (*Kn* = 1.012 and 1.006) and the gonadosomatic index (GSI = 5.41 and 4.96) for females and males of *A. surinamensis*, there were no distinctions between sexes and periods, thus demonstrating that samples had similar behavior in relation to the synchronism of the environment. In concordance with the anchovy species *Engraulis encrasicolus,* there were inter- and intra-annual variations of *Kn*, though these were in synchrony with the increase in GSI for this species population in the north-western Mediterranean Sea (Albo-Puigserver et al., 2020). This also corroborates with the values reported by Benchikh et al. (2018) for *E. encrasicolus* from the Gulf of Annaba, East Algeria, with GSI of 4.28 and *Kn* of 0.72. However, in our study, the analysis of energy expenditure with the reproductive processes of *A. surinamensis* was not performed for direct comparison with the *Kn* values, which may be a topic for future studies on the species.

Sexual maturation is also a very important transition phase in the life of fish (Fonteles-Filho, 1989) because, when the first maturation occurs, their energy reserves and time are destined for reproduction and survival (Azevedo et al., 2012). In the present study, the sexual maturation values for *A. surinamensis* were L_{50} (10.4 cm) and L_{100} (11.9 cm), indicating that most of the individuals of the Surinam anchovy were ready for reproduction in the low water period, which was also confirmed by the stages of the maturing gonads of these fish in the study region. On the other hand, the large number of mature individuals also found in the flood period indicates that the Surinam anchovy is a batch spawner, and is similar to its congeners (Alheit et al., 1983) and thus exhibiting a positive synchrony with the environment (Albo-Puigserver et al., 2020).

The growth performance index (GPI) is also a good way to evaluate the parameters of zootechnical performance of a species, since this value should not vary more than 5% when different populations of the same species are compared (Sparre and Venema, 1997). In the present study, the value found for the GPI was φ = 2.34, which suggests a satisfactory estimate of growth for the species *A. surinamensis*, though studies that can corroborate this result were not found in the literature for this species in the Amazon basin. However, our result was similar to that found by Cendrero et al. (1981) for *Engraulis encrasicolus* with φ = 2.34 belonging to the same family, but a different genus, caught in the Bay of Biscay (north-eastern Atlantic). However, Pertierra (1987), Bellido et al. (2000) and Benchikh et al. (2018) also studied *E. encrasicolus* and, by ELEFAN I method, obtained similar values for the GPI (φ = 2.21, φ = 2.51, and φ = 2.28), respectively. Similarities in GPI values between species may be an indication that the Surinam anchovy is well adapted to Amazonian lowland environments and that it makes good use of the resources available in these environments (Bornbusch, 1988).

When the estimated the growth rate (k = 0.70 $year^{-1}$) and longevity ($A_{0.95}$ = 4.28 $years^{-1}$) of the population of *A. surinamensis* of the Cujubim Lake were observed, it was found that these values were similar to those reported by Carvalho et al. (2018) for *Anchoa mitchilli* (k = 0.60, $A_{0.95}$ = 4.6 $year^{-1}$) and to data from Fishbase (Froese and Pauly, 2021) for *Anchoa spinifer* (k = 0.63, $A_{0.95}$ = 4.6 $year^{-1}$). Both species were caught at the Western Atlantic. Our results were also similar to those of Benchikh et al. (2018) for *Engraulis encrasicolus* (k = 0.60, $A_{0.95}$ = 4.92 $year^{-1}$) from the Gulf of Annaba, East Algeria, which indicates that these sardine populations of the family Eugraulidae have a similar growth rate and lifespan.

Changes in environmental patterns, such as seasonality in low water and flood, interfere with the behavior of the physicochemical variables of water (Correa et al., 2008; Bogotá-Gregory et al., 2020). As a result, these changes are reflected in the availability of primary foods, the basis of the Surinam anchovy food chain (Röpke et al., 2015), and may also interfere with the zootechnical development of fish and the condition factor values.

The physicochemical analysis of the water of the Cujubim Lake showed significant differences between the values of the studied parameters, though these variations occurred within the appropriate levels for the permanence of fish in tropical environments, both for periods of low water and for periods of flood (Kubitza, 1999, 2017). This environmental pattern indicates that the Cujubim Lake is suitable for the needs of *A. surinamensis* (Bornbusch, 1988), that the species has its population growth pattern dictated by the environment in terms of water level variation, food production and reproduction, which was also reflected in the similarity in the *Kn* values that are considered good for this species.

The Surinam anchovy found in the region of the Cujubim Lake is a fish that has ecological importance because it serves as a fodder species for larger fish. This statement is also reflected in the work of Agostinho et al. (1994). The results obtained in this research present relevant data for the understanding of the life cycle of the species

A. surinamensis of lowland areas of the Amazon (Queiroz et al., 2013), and indicate that this species has high reproductive activity in both evaluated seasonal periods (low water and flood). These results are similar to those found for the life cycle of Clupeiformes (high growth rate and fecundity, feeding at low trophic levels). The physico-chemical analyses of the water attest to the variability of the habitat imposed by the hydrological periods but did not impose adverse conditions for Surinam anchovy.

However, the present study rejects the null hypothesis, and confirms the adaptability of *A. surinamensis* to the Cujubim Lake, especially since the species is reproducing in both of the hydrological periods. It is confirmed by the macroscopic visualization of the maturation process of the gonads (observation of the external aspects) that allowed the verification of the specific maturation stages (Vazzoler, 1996). This was also reinforced by the values of the condition factor (*Kn*) and the presence of mature individuals in all collections. Therefore, the results suggest that *A. surinamensis* lives in a lake that has good availability of food resources (Mérona and Rankin-de-Mérona, 2004) and optimal environmental parameters for the maintenance of its population (Kubitza, 1999, 2017).

CONCLUSION

Our results regarding reproduction, population dynamics and environmental data indicate that *A. surinamensis* uses the area of the Cujubim Lake as a place of reproduction during periods of flood and low water. It also reveals that the physicochemical parameters of the lake water present seasonal variation, but that these do not exceed the limits required for survival of Neotropical fish, such as the Surinam anchovy. Thus, the present study presents baseline information for a better understanding of this natural resource that is of great importance for the maintenance of ichthyic biodiversity of the Amazon basin.

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Conflict of interests

Nothing to declare.

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Authors' Contributions

Dias, J.O.: conceptualization, investigation, methodology, visualization, writing – original draft. Amaral, R.V.A.: Data curation, investigation, methodology, original draft Writing. Sant'Anna, I.R.A.: formal Analysis, investigation, methodology, original draft Writing. Campo, C.P.: formal Analysis, methodology, original draft Writing. Lima, S.A.O.: Data curation, formal Analysis, investigation, methodology, Writing – original draft Writing. Sousa, R.G.C.: conceptualization, funding acquisition, investigation, methodology, project administration, visualization, writing – original draft, writing – review & editing.

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