

## **Reproductive biology and population parameters of commercially important Characiformes from the Araguari River, state of Amapá, Brazil**

**Biologia reprodutiva e parâmetros populacionais de Characiformes de importância comercial do Rio Araguari, Estado do Amapá, Brasil**

**Biología reproductiva y parámetros poblacionales de Characiformes comercialmente importante del Río Araguari, Estado de Amapá, Brasil**

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### **Abstract**

The present study aimed to estimate the length-weight relationship, relative condition factor (Kn), gonadosomatic index (GSI) and mean length at first maturity (L50) for 11 fish species serving as a subsidy for fisheries management of the Upper and Middle Araguari River. Samplings were conducted in the 2011-2014 period, with experimental fisheries and landing data; fish were measured (cm), sexed, and total weight (g) and gonad weight (g) were recorded. The length-weight relationship for all species had  $r^2$  above 0.76, indicating isometric growth for *A. inermis*, *A. falcatus*, *Charax sp.*, *L. melanosticus*, *L. maculatus*, *S. eingemani*. On the other hand, *H. aimara*, *B. cuvieri*, *M. asterias*, *M. romboidalis* and *M. ternetzi* showed allometric growth, the first two species with positive growth and the rest, negative. The combination of the relative condition factor (Kn) and the gonadosomatic index (GSI) was a good indicator of the reproductive period for *A. inermis*, *A. falcatus*, *B. cuvieri* and *M. ternetzi*. The estimated L50 values presented a minimum value of 12 cm for *M. asterias*, and a maximum of 28.6 cm for *H. aimara*. This study is of paramount importance for fisheries management and conservation of the studied area, especially as it is the first study for some species in the region.

**Keywords:** Length-weight relationship; Condition factor; L50; Gonadosomatic index; Reproductive period.

### **Resumo**

O presente estudo teve como objetivo estimar a relação peso-comprimento, fator de condição relativo (Kn), Índice gonadosomático (IGS) e comprimento médio de primeira maturação sexual (L50) para 11 espécies de peixes servindo como subsídio ao ordenamento pesqueiro do alto e médio rio Araguari. As coletas ocorreram entre 2011-2014 com pescarias experimentais e dados de desembarque, os peixes foram medidos (cm), sexados e registrados o peso total (gr) e o peso das gônadas (gr). A relação peso-comprimento para todas as espécies teve valor de  $r^2$  acima de 0,76 e constatou crescimento isométrico para *A.inermis*, *A. falcatus*, *Charax sp.*, *L. melanosticus*, *L. maculatus*, *S. eingemani*. Já *H. aimara*, *B. cuvieri*, *M. asterias*, *M. romboidalis* e *M. ternetzi* tiveram crescimento alométrico, sendo as duas primeiras espécies com crescimento positivo e o restante negativo. A combinação do fator de condição relativo (Kn) e do Índice gonadosomático (IGS) foi um bom indicador do período reprodutivo para *A. inermis*, *A. falcatus*, *B. cuvieri* e *M. ternetzi*. Os valores de L50 estimados apresentaram um valor mínimo de 12 cm para *M. asterias* e máximo de 28,6cm para *H. aimara*. Tal estudo é de suma importância para a gestão da pesca e conservação da área estudada especialmente por se tratar do primeiro estudo para algumas espécies na região.

**Palavras-chave:** Peso-comprimento; Fator de condição; L50; Índice gonadosomático; Período reprodutivo.

## Resumen

El presente estudio tuvo como objetivo estimar la relación peso-talla, el factor de condición relativa ( $K_n$ ), el índice gonadosomático (GSI) y la longitud media de primera maduración sexual (L50) de 11 especies de peces que sirven de subsidio a la planificación pesquera del río Araguari superior y medio. Las recolecciones se produjeron entre 2011-2014 con datos experimentales de pesca y desembarco, los peces fueron medidos (cm), sexados y se registró el peso total (gr) y el peso de las gónadas (gr). La relación peso-talla para todas las especies tuvo valores  $r^2$  superiores a 0,76 y se encontró un crecimiento isométrico para *A. inermis*, *A. falcatus*, *Charax* sp., *L. melanostictus*, *L. maculatus*, *S. eingemani*. Por otro lado, *H. aimara*, *B. cuvieri*, *M. asterias*, *M. romboidalis* y *M. ternetzi* tuvieron un crecimiento alométrico, con las dos primeras especies con crecimiento positivo y las restantes con crecimiento negativo. La combinación del factor de condición relativa ( $K_n$ ) y el índice gonadosomático (IGS) fue un buen indicador del periodo reproductivo para *A. inermis*, *A. falcatus*, *B. cuvieri* y *M. ternetzi*. Los valores estimados de L50 mostraron un valor mínimo de 12 cm para *M. asterias* y un máximo de 28,6 cm para *H. aimara*. Este estudio es de suma importancia para la gestión pesquera y la conservación de la zona estudiada, especialmente porque es el primer estudio para algunas especies en la región.

**Palabras clave:** Peso-talla; Factor de condición; Índice gonadosomático; Periodo reproductivo.

## 1. Introduction

Among aquatic vertebrates, fish represent one of the greatest biodiversity in the world, and South America has the greatest richness of these animals, in which the Amazon basin is home to around 2,416 species, of which 2,072 are considered endemic (Levequê et al. 2008). The Amazon has an extensive area of about 5,015,067.75 km<sup>2</sup>, and holds a large hydrographic network made up of several rivers. The Araguari River in the state of Amapá is 498 km long, its source is located Lombada Mountain Range and do Tumucumaque National Park Mountains, flowing into the Atlantic Ocean, between the municipalities of Serra do Navio, Pedra Branca do Amapari, Porto Grande, Ferreira Gomes, Cutias, Amapá and Tartarugalzinho, in addition to having three hydropower plants, Coaracy Nunes, Cachoeira Caldeirão and Ferreira Gomes, also delimiting several protected areas and conservation units, such as the Montanhas do Tumucumaque National Park, Amapá National Forest (FLONA), Amapá State Forest (FLOTA), one of the most protected units in the state, the Lago Piratuba and Parazinho Biological Reserves, and the Seringal Triunfo Private Natural Heritage Reserve (NHR) (Cunha, 2017).

One of the main challenges for fisheries in Amazon inland waters is the lack of information on the bioecology of fish species, especially those of commercial interest, which makes it difficult to monitor resources due to the lack of this information (Oliveira et al., 2018). In the Araguari River, there are several economic activities, including artisanal fishing. According to Oliveira et al. (2018), the most exploited fish in the Upper and Middle Araguari River region are: “trairão”, “curupeté”, “mandubé”, “pacu-mafurá”, “pacu-branco”, “traira-gapó”, “piranha”, “fusaca”, “tucunaré”, “branquinha”, “aracu cabeça gorda”, “uéua”. These fish are important for the communities inhabiting the region where they obtain their main source of protein and income (Oliveira et al., 2018).

Some reproduction and growth studies have already been carried out in the region, such as Soares et al. (2012), which evaluated the bioecology and ethnoecology of the fish fauna in FLONA; Cunha (2017), who worked on ethnoecology for socio-environmental preservation; Silva; Lima; Marinho (2018) showed spatial variation in the regional fishing activity due to operation of hydropower plants in the Araguari basin; Oliveira et al. (2018) reported artisanal fishing in the Upper and Middle Araguari; Prestes et al. (2019) examined the length-weight relationship for some species. However, information on reproductive biology, especially on commercially important species, is still scarce, despite their importance in decision-making by regulatory agencies (Nunes, 2015). Gama (2015) reported that length-weight relationship and condition factor of the species analyzed in the Araguari River region was not affected by the hydrological regime, but by the degree of preservation of the species. Therefore, understanding the biology and ecology of fish species, in particular reproduction, are important for understanding the behavior of populations, assisting proper management of resources, understanding the reproductive aspects is of great importance to fill gaps in the knowledge of the fish fauna (Nunes, 2015).

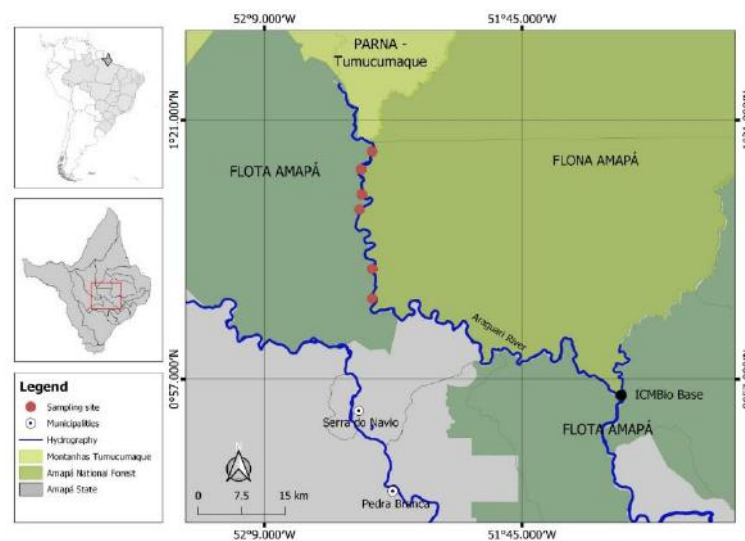
In this context, the present study aimed to evaluate data on reproductive biology and growth aspects to support the

fisheries management of the Upper and Middle Araguari River. In addition, future studies on the reproductive peculiarity of other species can contribute to produce significant data for the performance of fisheries management by agencies in the region.

## 2. Methodology

The study was carried out in the Upper and Middle Araguari River (Figure 1). Samplings were conducted from 2011 to 2012 in the rainy and dry seasons (2 samplings per season) using experimental fisheries, and monthly from March to November 2013, based on landing data at the base of FLONA in the state of Amapá. With the beginning of the close season and fishing closure, experimental fisheries were carried out in December 2013 and from February to June 2014.

**Figure 1** – Fishing sites in the Upper and Middle Araguari River, with the location of the Conservation and Sustainable Use Unit, Amapá National Forest - FLONA. State of Amapá, Brazil.



Source: Oliveira, (2021).

For collections, gillnets, hooks, traps, buoys were used in order to catch a larger number of specimens. Hooks and buoys were used in the morning, while nets at night, exposed for 12 hours and inspected every 6 hours. The specimens caught were identified in the field, biometric data were recorded for standard length (cm, ichthyometer), total weight (g, digital scale), sex and stages of gonad maturity; gonads were weighed in the field on a precision digital scale. The macroscopic identification of gonad maturity stages of females was performed according to the scale proposed by Vazzoler (1996): I (immature), II (maturing), III (mature or beginning of reproduction), IV (depleted) and V (rest). Variations in water level (cm) of the Araguari River for the 2011-2014 period was obtained from the National Water Agency (ANA) (<http://www.ana.gov.br>) and, with these data, the rainy (January - July) and dry (August - December) periods were determined. The length-weight relationship was estimated by linear regression with the transformed equation:  $\ln W_t = a + \ln L_s * b$ , where  $W_t$  is the total weight in grams,  $L_s$  is the standard length in centimeters,  $a$  and  $b$  are linear regression coefficients. Isometric growth was tested by Student's t-test, where:  $H_0 b = 3$  (isometric growth) and  $H_1 b \neq 3$  (allometric growth) (Le Cren, 1951). The mean length at first sexual maturity ( $L_{50}$ ) was determined by classifying females into two categories: young (I- immature) and adult (II- maturing, III- mature, IV- depleted and at rest) and, based on the relative frequency of young and adult females by length classes, the logistic function was estimated (King, 1995):  $y = 1/(1+\exp\{-(b_1) \times [x-(b_2)]\})$ , where:  $x$  = mean value of the length class (cm);  $y$  = relative frequency of adult females in the length class (%);  $b_1$  = non-linear regression coefficient; and  $b_2$  = mean length at first sexual maturity ( $L_{50}$ ) in centimeters.

The reproduction period was analyzed considering the Gonadosomatic Index (GSI):  $GSI = Wg/Wt*100$ , where:  $Wg$  is gonad weight (g) and  $Wt$  is total weight (g). The mean values of the relative condition factor ( $Kn$ ) were estimated through the equation (Le Cren, 1951):  $Kn = Wt/a*Lsb$ , where:  $Kn$  = relative condition factor;  $Wt$  = total weight;  $Ls$  = standard length and,  $a$  and  $b$  = constants obtained from the regression between weight and length. Regarding the monthly mean values of all collection years for GSI and condition factor ( $Kn$ ), the reproductive period was determined, and the constructed graphs considered the months referring to the rainy and dry periods in the Upper and Middle Araguari River. Analysis of L50 was run in the SizeMat package developed by Torrejon-Magallanes (2020), and the length-weight relationship was estimated using analysis routines in the R software (RCORETEAM, 2021). Values of the condition factor ( $Kn$ ) and the Gonadosomatic Index were calculated using the Microsoft Excel program (2013).

### 3. Results

In the Upper and Middle Araguari River, in the 2011-2014 period, a total of 1,329 individuals of 11 species were collected (Table 1). The frequency distribution of standard length (cm) presented a distribution with a tendency to normality. The length-weight relationship for all species had  $r^2$  value above 0.76 and indicated isometric growth for *A. inermis*, *A. falcatus*, *Charax sp.*, *L. melanostictus*, *L. maculatus* and *S. eingenmanni*. On the other hand, *H. aimara*, *B. cuvieri*, *M. asterias*, *M. romboidalis* and *M. ternetzi* showed allometric growth, the first two species with positive growth and the rest, negative, as presented in Table 1.

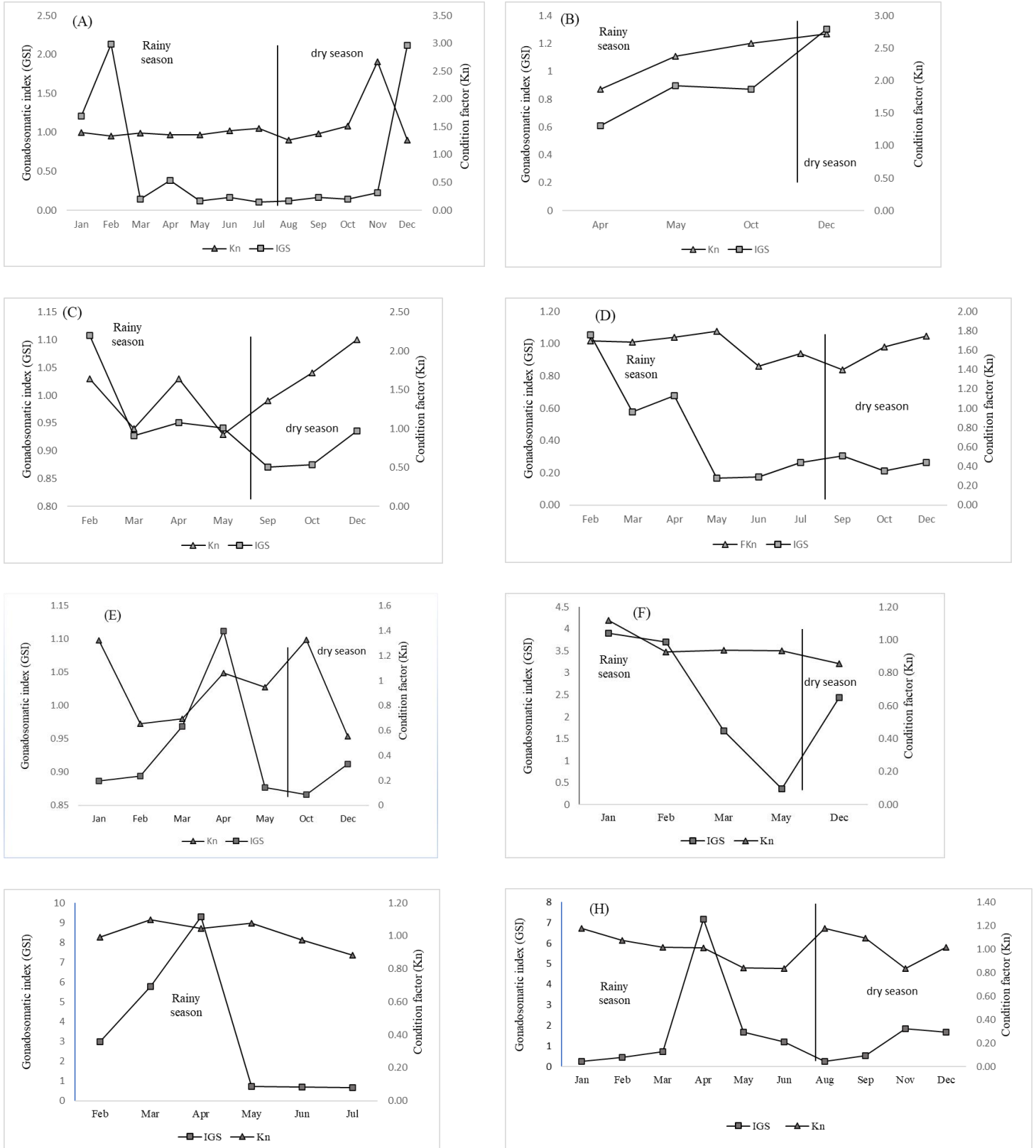
The relative condition factor ( $Kn$ ) for all species, with the exception of *Charax sp.* and *M. asterias*, had values close to or above 1. *A. inermis*, *H. aimara*, *A. falcatus*, *B. cuvieri*, *L. maculatus*, *M. asterias*, *M. ternetzi* and *S. eingenmanni* showed an increase in the value of relative condition always in the dry season and decrease in values in the rainy season. On the other hand, *Charax sp.*, *L. cf. melanostictus* e *M. cf. romboidalis* showed an increase in the rainy season and a decrease in the dry season (Figure 1).

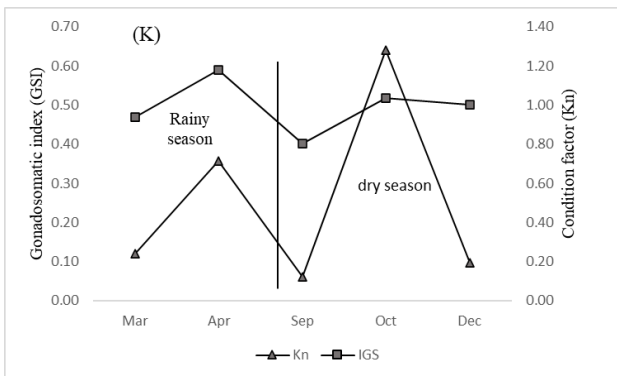
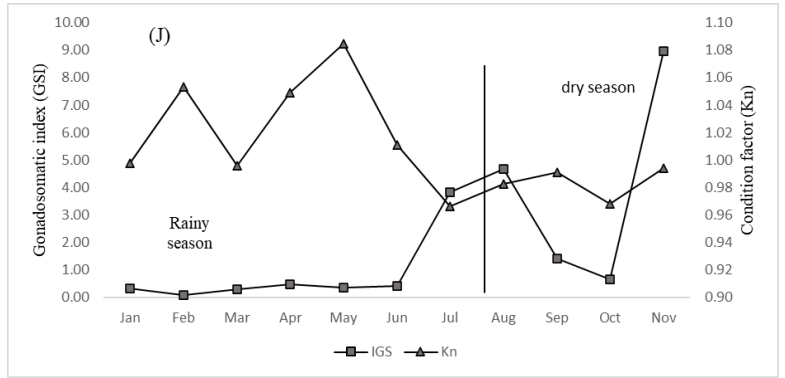
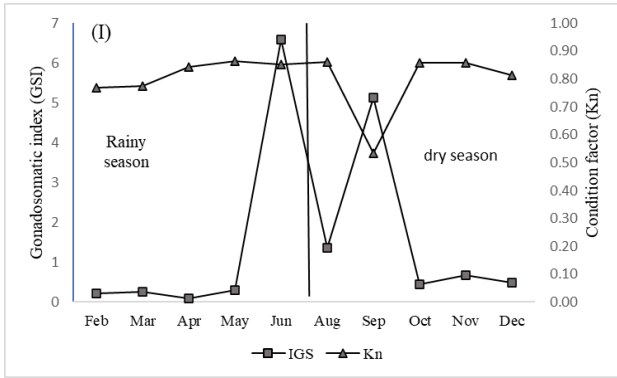
**Table 1.** Length-weight–relationships of fish species caught in the Upper and Middle Araguari River, Macapá, state of Amapá. N, number of species caught; mean and standard deviation of standard length (Ls) and total weight (Wt); r<sup>2</sup>, coefficient of determination of length-weight relationships; a, intercept; b, slope; type of growth; t-test (p-value); size of first sexual maturity (L50); 95% confidence interval for L50.

Species	N	Ls (cm)	Wt (g)	r <sup>2</sup>	a	b	Type of growth	t-test (p-value)	L <sub>50</sub> (cm)	95% Confidence Interval L <sub>50</sub> (cm)
<i>Hoplias aimara</i>	132	42.2 ± 10.4	1830.4 ± 1151.7	0.98	0.0141	3.10	Allometric +	< 0.0002	28.6	26.7 - 30.5
<i>Ageneiosus inermis</i>	190	34.0 ± 6.4	532.5 ± 369.9	0.93	0.0133	3.01	Isometric	0.730	23.6	23.1 - 24.2
<i>Acestrorhynchus falcatus</i>	88	15.5 ± 2.9	39.0 ± 38.8	0.87	0.0148	2.89	Isometric	0.380	15.4	15.2 - 15.7
<i>Boulengerella cuvieri</i>	107	42.0 ± 10.7	626.0 ± 604.0	0.98	0.0023	3.33	Allometric +	< 0.0001	26.7	23.1 - 28.6
<i>Charax</i> sp.	53	17.0 ± 2.9	106.0 ± 45.4	0.94	0.0211	2.96	Isometric	0.740	14.9	14.2 - 15.4
<i>Leporinus</i> cf. <i>melanostictus</i>	85	23.0 ± 3.8	300.0 ± 105.2	0.87	0.0434	2.82	Isometric	0.149	17.7	17.0 - 18.0
<i>Leporinus maculatus</i>	71	12.0 ± 1.0	31.0 ± 8.3	0.96	0.0223	2.94	Isometric	0.420	13.3	13.0 - 16.4
<i>Myloplus asterias</i>	314	15.5 ± 2.1	177.0 ± 61.9	0.76	0.1670	2.52	Allometric -	< 0.0001	12.0	11.6 - 12.4
<i>Myloplus</i> cf. <i>rhomboidalis</i>	106	27.7 ± 3.2	965.5 ± 309.9	0.87	0.1400	2.65	Allometric -	< 0.0001	-	-
<i>Myloplus ternetzi</i>	115	18.0 ± 1.9	245.0 ± 63.4	0.82	0.2138	2.42	Allometric -	< 0.0001	-	-
<i>Serrasalmus eingenmanni</i>	68	15.0 ± 3.0	120.5 ± 85.7	0.92	0.0528	2.85	Isometric	0.134	-	-

Source: Authors. Fauro *et al.*, (2022).

**Figure 2** – Condition factor (Kn) and gonadosomatic index as indicator for the reproductive period for the species (A) *A. inermis*, (B) *A. falcatus*, (C) *B. cuvieri* (D), *M. ternetzi*, (E) *H. aimaras*, (F) *Charax* sp., (G) *Leporinus* cf. *melanostictus*, (H) *Leporinus maculatus*, (I) *Myloplus asterias*, (J) *Myloplus* cf. *rhomboidalis* and (K) *Serrasalmus eingenmanni*. The graphics shows the data per months grouped four years (2011-2014).





Source: Authors. Fauro *et al.*, (2022).

*A. inermis*, *A. falcatus*, *B. cuvieri*, *M. rhomboidalis*, *Charax sp.* and *M. ternetzi* presented higher values of the Gonadosomatic Index (GSI) from December to February (late dry season and early rainy season). *M. asterias* had higher values from June to September (late rainy season and early dry season). *H. aimara*, *L. melanostictus*, *L. maculatus* and *S. eingenmanni* showed higher values from March to May (rainy season).

The estimated L50 values presented a minimum value of 12 cm for *M. asterias* and a maximum of 28.6 cm for *H. aimara* (Table 1). For *M. rhomboidalis*, *M. ternetzi* and *S. eingenmanni*, it was not possible to estimate the L50 values, as they do not present immature individuals in the collected data.

#### 4. Discussion

*A. falcatus*, *Charax sp.*, *L. melanostictus*, *L. maculatus*, *M. asterias*, *M. ternetzi*, *S. eingenmanni*, *M. rhomboidalis* and *A. inermis* are considered medium-sized, and *H. aimara* and *B. cuvieri*, large-sized. Data on measured standard length were representative for the 11 species, as the length frequency distributions tended towards normality. It is important to point out that for *Charax sp.*, *M. rhomboidalis*, *B. cuvieri*, *L. melanostictus*, *L. maculatus* and *S. eingenmanni*, the present study brings the first estimates of length-weight relationship, condition factor and L50 for the Araguari River basin.

Linear regression analyses between weight and length indicated that the models explained at least 76% of all the variability of response data around their mean, which is expected in analysis using length-weight. The length-weight is of great importance as it describes aspects of the biology and ecology of the species (Vazzoler, 1996). The value of coefficient (b) of the species ranged from 3.33 to 2.42, within the expected pattern for both Le Cren (1951) and Froese (2006). Isometric growth was observed in the investigated species with elongated body, *A. inermis*, *A. falcatus*, *Charax sp.*, *L. melanostictus*, *L. maculatus*, except for *S. eingenmanni*, with a tall, rounded body. Deviations observed in the value of b for species showing



isometric growth may be associated with the size sample and amplitude of the individuals sampled. *H. aimara*, *B. cuvieri*, *M. asterias*, *M. rhomboidalis* and *M. ternetzi* showed allometric growth, the first two species with positive allometry and the rest, negative. These values are consistent with those obtained by Prestes et al. (2019) for *M. asterias*, and *M. ternetzi* in the Upper and Middle Araguari River region. As for *H. aimara* and *A. inermis*, the growth pattern was different from that reported by Prestes et al. (2019). *B. cuvieri* from the Tarumã River (Da Costa & Neto dos Santos Nunes, 2019) presented values very different from those found in the present study, with *b* values between 1.56 and 2.10. However, the study was carried out in different basins, as well as the values of *b* detected in the Tarumã study are outside the standard proposed by Froese (2006). It is noteworthy that the sampling of this study was more robust than all the other studies compared here.

The condition factor values were high for most species and varied according to the seasons. However, there was variation among species with high values both in the rainy season for *A. inermis*, *A. falcatus*, *B. cuvieri* and *M. ternetzi* as well as in the dry one for *Myloplus* cf. *rhomboidalis*, *L. maculatus*. This is probably related to the reproductive period of each species. Vazzoler (1996) argues that seasonality in aquatic ecosystems influences the reproductive periods and feeding frequency of fish species. Another noteworthy aspect is that most species presented values close to or above 1. As it is a conservation area (FLONA), it can be assumed that the condition factor values are related to the preservation of the area.

Determining the reproductive period and sexual maturity are essential for fisheries science and for understanding the life cycle of fish (Sivakumarana et al., 2003). The analyses point out the relationship between the gonadosomatic index and the condition factor as a good indicator of the reproduction period for *A. inermis*, *A. falcatus*, *B. cuvieri* and *M. ternetzi*. The gonadosomatic index (GSI) is an auxiliary data widely used for determination of the stages of the reproductive cycle of fish, because the maturity of reproductive cells occurs concomitantly with the increase in gonad weight and the condition factor is a quantitative indicator of the momentary welfare in fish, which varies during the individual's sexual maturity cycle, therefore, can be influenced, among other factors, by the variation in gonad weight (Vazzoler, 1996).

The L50 is an estimate of the size of a given species, in which 50% individuals are at the mature stage. Determining the minimum length at sexual maturity for communities of aquatic animals is an important tool in choosing measures to control overfishing, as it is possible to indicate the suitable catch size as well as adjust fishing gear to the appropriate size (King, 1997). It is important to point out that these are the first estimated L50 values for the species in the region, making comparisons with other studies impossible for most species. Only *A. falcatus* presented L50 values similar to data reported by Soares et al. (2008) in lakes of the Middle Solimões River.

## 5. Conclusion

The goals of these paper were achieved, the information about biological aspects of fish from the Upper and Middle Araguari River provides important targets for fisheries management and conservation in the studied area. The research will be moving forward in the management plans of fisheries using these informations, however, that was the first scientific data for many of fish species and monitoring the evaluation of these targets, mostly because the constructions of damns changing the habitats of these species. These results can be used to building a database for the Araguari basin and to guide the decision making.

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