Original article

Population and reproductive parameters of the red-tailed catfish, *Phractocephalus hemioliopterus* (Pimelodidae: Siluriformes), from the Xingu River, Brazil

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A field study of the sex ratio, length-weight ratio, body size at first gonadal maturation, and the breeding season of the red-tailed catfish, *Phractocephalus hemioliopterus*, was carried out in the region of the middle Xingu River in the eastern Amazon basin. The fish were sampled quarterly from September 2012 to January 2014 using gillnets and long lines. The sex ratio was balanced, and while males and females were similar in standard length, the females were heavier than the males, on average. The males presented negative allometric growth, and the females, isometric growth. The estimated size at first maturity was 77.8 cm. The variation in the gonadosomatic index and the greater frequencies of mature specimens indicated a reproductive peak at the beginning of the high-water (flood) period. As *P. hemioliopterus* is an important commercial fish, our findings will contribute to the future development of effective conservation and management strategies, such as minimum catch size and a close season that is appropriate for the region. These data will also provide important insights for the evaluation of potential impacts on the biology of this fish resulting from the construction of Belo Monte dam.

Keywords: Amazon basin, Breeding season, Fishery, Gonadal maturity, Growth pattern.

Um estudo de campo sobre a proporção sexual, relação peso-comprimento, tamanho de primeira maturação gonadal e o período reprodutivo da pirarara, *Phractocephalus hemioliopterus* foi realizado na região do Médio Rio Xingu, na Amazônia oriental. Os espécimes foram coletados trimestralmente entre setembro de 2012 e janeiro de 2014, utilizando redes malhadeiras e espinheis. A proporção sexual foi balanceada, e machos e fêmeas foram equivalentes quanto ao comprimento padrão, mas fêmeas foram mais pesadas do que machos. Crescimento alométrico negativo foi evidenciado para machos e crescimento isométrico para fêmeas. O tamanho estimado de primeira maturação sexual foi igual a 77,8 cm. A variação do índice gonadossomático e a maior frequência de indivíduos maduros evidenciaram uma maior atividade reprodutiva no começo do período de águas altas (enchente). Considerando *P. hemioliopterus* como uma espécie de interesse comercial, as informações aqui apresentadas poderão ser uteis para um futuro plano de conservação e manejo como o estabelecimento de um tamanho mínimo de captura e período de defeso para a região. Além disso, poderá ser útil para avaliar potenciais impactos na biologia dos peixes em decorrência das mudanças ambientais provocadas pela construção da barragem de Belo Monte.

Palavras-chave: Bacia Amazônica, Maturação Gonadal, Padrão de crescimento, Período reprodutivo, Pesca.

Introduction

The family Pimelodidae comprises more than one hundred valid species of freshwater fish (Frickle *et al.*, 2019), which are all endemic to the Neotropics, with the highest diversity being found in the Amazon, Paraná and Orinoco basins, and the principal rivers of the Guianas (Lundberg, Littmann, 2003). The adult fishes of this family vary considerably in body length, ranging from 20 cm to over two meters. Many of the larger pimelodid species are long-distance migrators (Godinho, Kynard, 2009; Hauser *et al.*, 2018) that travel considerable distance to spawn, and are an important source of animal protein for many human populations throughout tropical South America. These fish are mainly species of the genera *Brachyplatystoma* and *Pseudoplatystoma* (Barthem, Goulding, 1997; Barthem *et al.*, 2017; Pérez, Fabré, 2018).

The giant red-tailed catfish, *Phractocephalus hemioliopterus* (Bloch, Schneider, 1801), known as the "pirarara" in Brazil, is widely distributed in the Amazon and Orinoco basins. This species is a medium-distance migrator, typically traveling 100-1,000 km, is also one of the most important species for sport and commercial fisheries (Carolsfeld *et al.*, 2003; Barletta *et al.*, 2015; Mesquita,

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Isaac-Nahum, 2015). The potential yield of the species in the Amazon region was estimated to be almost 900 tons per year (Barthem, Goulding, 2007). Despite this interest, the species has not yet been assessed for the IUCN Red List of Threatened Species (IUCN, 2019), even though its natural stocks may be at risk from increasing of human interference in recent decades, in particular, the damming of the major rivers of the Amazon basin (Winemiller *et al.*, 2016; Forsberg *et al.*, 2017), which threaten local biological cycles. In general, impoundment alters the local hydrological regime, including the intensity and periodicity of the flood pulse, which is an important trigger for final oocyte maturation, as well as disrupting migration routes to spawning areas and feeding grounds (Vazzoler, 1996; Antonio *et al.*, 2007).

In the context of these effects of river impoundment, studies of the reproductive biology of fishes constitute an essential tool for the better understanding of population dynamics related to the seasonal variation in the environmental factors observed in aquatic ecosystems (Freitas *et al.*, 2015; Barbosa *et al.*, 2018). In the Amazon basin, this seasonality is derived naturally from the hydrological oscillations of the flood pulse (Junk *et al.*, 1989), which plays a significant role in the maturation of fish gonads, the spawning season, and larval development (Goulding, 1980; Zeug, Winemiller, 2008).

Despite the ecological and economic relevance of *P. hemioliopterus*, few data are available on this species, and the limited number of available studies have focused on its piscivorous feeding habits (Barbarino-Duque, Winemiller, 2003), parasitology (De Chambrier *et al.*, 2005), length-weight and length-length relationships (Giarrizzo *et al.*, 2015), biotelemetry (Hahn *et al.*, 2015), and cytogenetics (Swarça, 2017), and no studies have focused on

the reproductive biology of the species. Given this, the present study investigated the population parameters and reproductive patterns of *P. hemioliopterus* in the region of the middle Xingu River, in the eastern Amazon basin. The study evaluated the sex ratio, length-weight relationship, size at first maturity, and breeding season of *P. hemioliopterus* in this region, where one of the largest hydropower installations in South America, the Belo Monte Dam, was recently constructed (Winemiller *et al.*, 2016). The results of this study provide crucial data from the period prior to the impoundment and serve as a baseline for further comparisons and decision-making on the management of local fishery stocks.

Material and Methods

Sampling sites. The Xingu River is a clear-water system characterized by low pH, conductivity, and suspended solid concentrations, and is one of the most important right-bank tributaries of the Amazon River. In the region of the middle Xingu River (near the city of Altamira; 3º12'52" S, 52º11'23" W) (Fig. 1), the climate is tropical hot and humid, Am type in the Köppen-Geiger classification (Peel *et al.*, 2007). The predominant vegetation is typical lowland Amazon rainforest (Barbosa *et al.*, 2018). The annual fluviometric variation recorded on the river can be divided into four distinct hydrological periods: the dry (September-November), filling (December-February), flood (March-May), and receding (June-August) (see Barbosa *et al.*, 2015; 2018). The fluviometric data were obtained from the Brazilian National Waters Agency ("Agência Nacional de Águas", ANA, 2018).
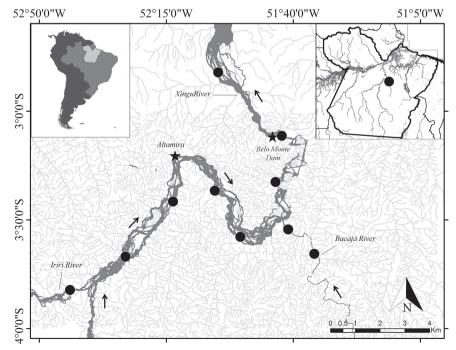

Fig. 1. Study area on the middle Xingu River in Pará, Brazil. The black dots represent the sampling sites, and the arrows indicate the direction of the water flow.

Collection of fish specimens. Specimens of *P. hemioliopterus* were collected quarterly from September 2012 to January 2014, using gillnets of ten different mesh sizes (20-180 mm stretch meshes), and long lines with 30 hooks (sizes 12⁄0 and 14⁄0), cast under the guidance of a local fisherman and set for twelve hours per day (18:00 h to 06:00 h). Fish were sampled according to the environmental monitoring guidelines of the Belo Monte Dam (for further details of the sampling methods, see Barbosa *et al.*, 2015). The specimens captured were measured to determine their standard length (S_L; 0.1 cm), and weighed to establish total mass (T_M; 0.1 g) and gonadal mass (G_M; 0.1 g). We determined the sex and gonadal maturation of each specimen through a visual macroscopic analysis of the gonads, based on the protocol of Vazzoler (1996), which classifies the fish as stage I (immature); stage II (maturing); stage III (mature); and stage IV (at rest or empty). Voucher specimens were fixed in 10% formalin for 48 h, transferred to 70% ethanol for storage, and deposited in the Laboratory of Ichthyology of Altamira (in Portuguese 'LIA') in Altamira (Pará, Brazil) under numbers LIA 389 and LIA 790. The Ethics Committee of the Universidade Federal do Pará approved the collection and conservation of the fish specimens (protocol CEUA nº 8293020418).

Data analysis. Sex ratio and length-weight relationship. The bias in the sex ratio during the different study periods was evaluated using Chi-square (X^2). Differences in body length and weight were evaluated by the *t* test. The length-weight relationship (LWR) adhered to the model first proposed by Järvi (1920) (see Froese, 2006), where T_M is the total mass of the specimen and S_L is its standard length. Parameter *a* is the coefficient of proportionality, and *b* is the coefficient of allometry, where *b* can also be interpreted as the fish growth type (Froese, 2006). After pooling the LWRs for the two sexes, sexual differences in growth patterns were assessed based on the comparison of length residues ([observed-predicted]/predicted) using the t test (see Fontoura, Conter, 2008; Freitas *et al.*, 2016). When differences between the sexes were identified, the LWRs were calculated separately for males and females. To define the growth type of *P. hemioliopterus*, the *b* values were evaluated using a *t* test, comparing the observed value with a hypothetical *b* value of 3, which defines isometric growth (Froese, 2006), that is, when length and weight vary proportionately. Negative allometry occurs when body length increases at a faster rate than weight (*b* < 3), while positive allometry occurs when weight increases at a faster rate than body size (*b* > 3) (Froese, 2006).

First sexual maturation. Size at first sexual maturation (L_{50}) was estimated based on the logistic equation of Trippel, Harvey (1991), where P = the proportion of reproductive adults in each size class, A = the asymptote of the curve (A = 1), r = the rate of change between non- reproductive and reproductive individuals, S_L = the standard length (cm) in the size classes, and L_{50} = the size (cm) at which 50% of

the individuals reach sexual maturity. The gonadossomatic index (GSI) was used for this analysis, and was obtained through the formula; where G_M is the weight of the gonads (g) and T_M is the total mass of the individual (g). These values were then transformed into a percentage of the maximum recorded value, and the specimens were binarized as reproductive or non-reproductive. As proposed by Fontoura *et al.* (2009), all individuals with GSI values equal to or greater than a certain percentage of the maximum GSI were considered to be involved in the reproductive process. Here, we applied a criterion of 5% to determine the reproductive status of a specimen, that is, any individual with a GSI of less than 5% of the maximum value recorded was classified as non-reproductive, with all other individuals (> 5% of the maximum GSI) being considered reproductive. The equation parameters were estimated from the data set organized in 10 cm length classes using a non-linear regression routine run in R (R Development Core Team, 2015). To avoid possible sampling effects, the L_{50} analysis was run with both sexes pooled.

Reproductive activity. The breeding season was determined through the seasonal variation in the gonadosomatic index (GSI) recorded during each study period, also for the pooled data (both sexes). Higher GSI values indicate greater reproductive activity. The GSI values were adjusted using a sinusoidal function, as proposed by Fontoura, Agostinho (1996) (applied by Freitas *et al.*, 2011), which describes seasonal (cyclic) variation based on the formula: where M = global mean GSI, A = amplitude of the variation in GSI, Frq = unit of time in which the events were measured (Frq = 12 when the time is measured in months), t (time) = numerical time scale (here, January = 1, February = 2, March = 3… December = 12), and f (phase) = the difference between the baseline time (zero) and the time with the maximum mean GSI value (representing the sinusoid). In this case, the phase also represents the month of the year with the largest estimated GSI values. A coefficient of determination (R^2) was calculated for the sinusoidal model by the ratio of the sum of the squares of the residuals to the total sum of squares, with the p-values being obtained using a significance test based on the F statistic. All the parameters of the sinusoidal function were estimated by using the Solver tool of Microsoft Office Excel® 2010. The relative frequencies of the gonadal maturation stages and local fluviometric levels were recorded in each study period. A 5% significance level was considered in all analyses (Zar, 2010).
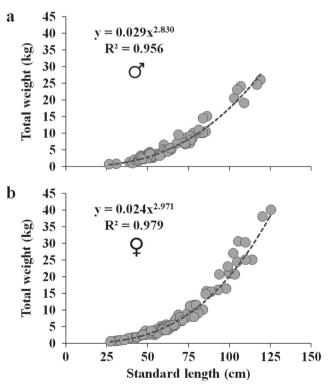
Results

A total of 154 *P. hemioliopterus* specimens were collected during the study period, of which, 66 were male and 88 were female. The sex ratio was balanced in most study periods (Tab. 1), but biased significantly toward the females in the dry season of 2012 (χ^2 = 4.296, p = 0.038) and toward the males in the filling season of 2014 (χ^2 = 4.416, p = 0.036).

Tab. 1. Sex ratio of the red-tailed catfish, *Phractocephalus hemioliopterus*, specimens collected from the Xingu River in Pará, Brazil. *indicates a significant difference between males and females.

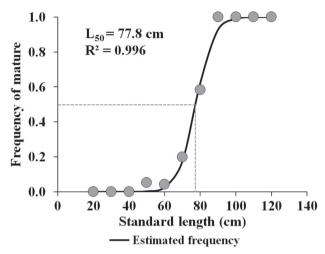| Sex | 2012 | | 2013 | | 2014 | | Total |
	Dry	Filling	Flood	Receding	Dry	Filling	
Males	22	12	7	8	6	11	66
Females	40	9	12	13	8	6	88
Chi-square (χ^2)	4.296	1.018	3.553	2.873	1.018	4.416	1.018
p	0.038*	0.313	0.059	0.090	0.313	0.036*	0.313

Body length did not vary significantly between the sexes ($t = 1.144$, $p = 0.096$). The mean total length of the males was 63.5 ± 20.4 cm (range 26.5-119.0 cm) and that of the females was 68.0 ± 21.9 cm (range 27.3-125.4 cm). By contrast, females were significantly heavier than males ($t = 1.860$, $p = 0.033$), with a mean weight of 8.7 ± 8.7 kg (range 0.6-40.0 kg) compared with 6.7 ± 6.1 kg (range 0.7-26.6 kg) in the males.

The analysis of the LWR revealed a clear gender bias in growth patterns ($t = 1.921$, $p = 0.029$), which indicated the need for the application of distinct equations. For the males, the LWR was established through the equation $T_M = 0.029*S_L^{2.830}$ ($R^2 = 0.956$) (Fig. 2a), while for females, the formula was $T_M = 0.024*S_L^{2.971}$ ($R^2 = 0.979$) (Fig. 2b). The LWR indicated negative allometric growth in the males ($b = 2.830$, $t = 2.984$, $p = 0.002$) and isometric growth in the females ($b = 2.971$, $t = 0.426$, $p = 0.336$).
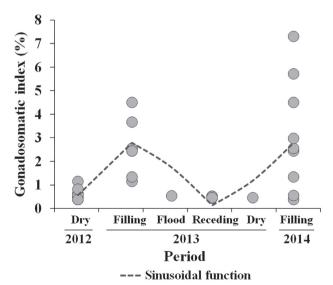

Fig. 2. Length-weight relationship of the red-tailed catfish *Phractocephalus hemioliopterus* specimens collected from the Xingu River in Pará, Brazil. **a.** males; and **b.** females.

To avoid diluting the number of adults specimens (15 males and 21 females) among the different length classes – considering the 5% criterion of the maximum GSI – we pooled the two sexes to estimate the size at the first sexual maturation (L50) of *P. hemioliopterus*, which was 77.8 cm (lower limit = 76.3 cm; upper limit = 79.3 cm; $R^2 = 0.996$) (Fig. 3).

Fig. 3. Size at first sexual maturity in the red-tailed catfish *Phractocephalus hemioliopterus* specimens collected from the Xingu River in Pará, Brazil.
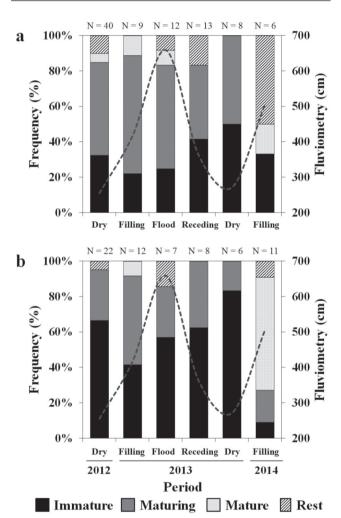
Seasonally, we recorded a reproductive peak (pooled data) in the filling period of 2014 ($p = 0.042$, F = 6.323, Fig. 4), with a mean GSI of 3.07. The phase parameter of the sinusoidal equation ($f = 1.38$) indicated that reproductive activity occurs primarily between January and February (see Tab. 2). We also observed a higher frequency of individuals in the mature and rest gonadal stages during the filling season of 2014 (Fig. 5), which corroborates the sinusoidal analysis.

Fig. 4. Variation of the gonadosomatic index (GSI) of adult (reproductive) red-tailed catfish *Phractocephalus hemioliopterus* specimens collected from the Xingu River, in Pará, Brazil.

Tab. 2. Parameters of the sinusoidal equation for the Gonadossomatic Index (GSI) values recorded for the red-tailed catfish, *Phractocephalus hemioliopterus*, specimens collected from the Xingu River in Pará, Brazil. *indicates a seasonal trend in the curve.

Parameters	Pooled sample
Amplitude (*A*)	1.354
Mean (*M*)	1.463
Phase (*f*)	1.385
R²	0.449
P value	0.042*

Fig. 5. Relative frequency (%) of the different gonadal maturation stages of the red-tailed catfish *Phractocephalus hemioliopterus* specimens collected from the Xingu River in Pará, Brazil. **a.** males; and **b.** females.

Discussion

The present study determined the sex ratio, growth parameters, first sexual maturation, and reproductive season of *Phractocephalus hemioliopterus* from the middle Xingu River. No bias was found in the sex ratio for the study period as a whole, although a female bias was recorded during the dry periods, and a male bias during the filling period. Veloso-Junior *et al.* (2014) observed cohorts separated by sex and season in the pimelodid *Pimelodus pohli* Ribeiro, Lucena, 2006, and Figueiredo *et al.* (2018) also observed this pattern in other siluriforms. The results of the present study indicate that *P. hemioliopterus* may be segregated by sex with peaks of reproductive activity.

Sexual dimorphism was found in *P. hemioliopterus*, and has also been recorded in other pimelodids (Paschoalini *et al*, 2013; Suzuki *et al.*, 2013; Barzotto *et al.*, 2017). While the length did not vary between sexes, the female *P. hemioliopterus* were heavier than the males, presumably due to their greater energetic investment in the reproductive process, in particular, the production of eggs (Bromley, 2003; Prudente *et al.*, 2014; Barneche *et al.*, 2018). This pattern is relatively common in fish, given that the fertility of the female increases with body size (Bisazza, Pilastro, 1997; Murua, Saborido-Rey, 2003).

The negative allometry recorded in the LWR of the males indicates that their body length grows faster than their weight, whereas the females presented isometric growth. These sexual differences in growth patterns can also be related to reproductive strategies, that is, the faster growth in length would allow males to mature earlier, and then compete more effectively with other males for sexual partners (García-Vásquez *et al.*, 2009; Freitas *et al.*, 2015).

The L_{50} estimated for *P. hemioliopterus* was standard length of almost 80 cm. Given the small number of adult specimens available in the present study, the size at first sexual maturity was estimated for males and females together. A much larger number of adult specimens would be recommended for the reliable determination of body size at first sexual maturation for each sex separately. However, our L_{50} is consistent with the values recorded for *P. hemioliopterus* from Bolivian river basins by Sarmiento *et al.* (2014), who established that maturation occurred at a length of 65-85 cm. As the L_{50} value indicates the body size at which 50% of the individuals are new recruits, this value provides important insights for fish stock management, in particular, the definition of a minimum catch size, which would allow smaller fish to reach reproductive age (in this case, based on their body length). The L_{50} value obtained here for *P. hemioliopterus* is in agreement with Brazilian national and state legislation, which determine a minimum capture size of 80 cm for *P. hemioliopterus* in the Tocantins-Araguaia river basins (Brasil, 2011a; 2011b), 90 cm for individuals caught in the Brazilian state of Mato Grosso (Tiago, 2011), and 70 cm for the Colombian Amazon basin (Carolsfeld *et al.*, 2003). No specific legislation applies to the Xingu River, however, which is preoccupying for the preservation of local aquatic biodiversity. This information is useful to prevent overfishing and the depletion of natural stocks by defining an effective cut-off size for fishery exploitation (Trippel, 1995; Hauser *et al.*, 2018).

The red-tailed catfish presented a peak in reproductive activity (as indicated by the GSI values and the increased frequency of mature individuals) at the beginning of the filling period. This period favors the reproduction of many fish species (Bailly *et al.*, 2008), through the inundation of the flood plain and adjacent forests, providing new habitats for feeding and nurseries (Goulding, 1980). Many pimelodid fish are known to migrate several hundreds of kilometers to spawn (Barthem *et al.*, 2017), and *P. hemioliopterus* appears to migrate as the water level is rising (Carolsfeld *et al.*, 2003), which coincides with the timing of the breeding season recorded here. The reproductive behavior of *P. hemioliopterus* is still unclear, but the species is not captured in large schools, and probably migrates to spawn in the white-water rivers of the Amazon floodplain, given that juvenile specimens have never been registered in black or clear-water rivers (Barthem, Goulding, 2007).

A number of authors have also recognized the importance of the flood pulse for the reproduction of pimelodids (Holzbach *et al.*, 2009; Suzuki *et al.*, 2013; Barzotto *et al.*, 2017). In the Amazon, in particular, many high-value species that migrate hundreds of kilometers in response to the seasonal flood pulse (*e.g. P. hemioliopterus*) will be threatened seriously by environmental changes driven by human interference, such as river impoundment (Winemiller *et al.*, 2016; Barthem *et al.*, 2017; Forsberg *et al.*, 2017). This abrupt and permanent intervention in the characteristics of physical habitats may affect the reproductive and recruitment patterns of most fish species (Agostinho *et al.*, 2004). In particular, migratory fish, like *P. hemioliopterus*, may be prevented from completing their reproductive migrations due to the obstruction of the river, which impedes the fish from reaching suitable spawning locations (Antonio *et al.*, 2007; Pelicice *et al.*, 2018), which could eventually lead to local population decline and even extinction.

The impoundment of rivers is known to have devastating effects on fish biology (Agostinho *et al.*, 2016), in particular for migratory fish which are considered to be umbrella species for the protection of aquatic environments (Agostinho *et al.*, 2005). The results of the present study provide important insights for the regulation of local *P. hemioliopterus* fisheries on the Xingu River, including a minimum catch size and a close season. These data are especially relevant to *P. hemioliopterus*, which is a species of high commercial value, and is also prized by sport fishers. However, the data cannot be extrapolated to the other migratory species of the Xingu basin, given that each fish has its own intrinsic characteristics, nor can it be extrapolated to the *P. hemioliopterus* stocks in other basins, given the distinct biological and geomorphological features of these systems. The findings of the present study nevertheless provide important insights for the development of effective conservation and management strategies for the fish populations impacted by the impoundment of the middle Xingu River, and potentially also for the Amazon basin as a whole.

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