

Do hydroelectric dams affect the abundance and population structure of freshwater shrimps?

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ABSTRACT. Freshwater shrimps play an important role in many ecological processes since they are epibenthic detritivores but also prey on other invertebrates and are predated by fishes. The knowledge about their biology allow the development of management strategies to improve the use of natural resources by avoiding overfishing and enhancing productivity. Here we evaluated the population structure of the shrimp *Macrobrachium amazonicum* in the river Rio Grande, upstream of the Água Vermelha hydroelectric dam. They were captured monthly from October 2017 until March 2018, in six sites along the river. The first site was ~1000 m distant from the dam and the sixth was ~4000 m distant. A sac-like sieve and traps were used to capture the shrimps. The sieve was dragged three times for 180°. The traps were left by the river margins for six hours. In the laboratory, the shrimps were sexed and measured (carapace length; CL). In total, 6455 individuals were captured: 4499 females (294 breeding), 1445 males, and 217 juveniles. Female mean size was 7.50 ± 3.47 mm, male mean size was 7.44 ± 2.40 mm, and juvenile mean size was 3.24 ± 1.10 mm. The smallest individual was found in site III and it was a juvenile of 1.08 mm. The largest had 20 mm and was found in site II. The smallest breeding female had 3.8 mm CL. The largest individuals were more abundant in the sites near the dam, whereas the smallest were more abundant in the farthest sites. The highest abundance was seen in sites III and IV, and the lowest, in site VI. Unlike males and juveniles, females (both breeding and non-breeding) were more abundant (Anova, $p < 0.01$) near the dam. By knowing the population structure of *M. amazonicum* it is possible to understand how they are being affected by the environmental changes caused by the hydroelectric dam.

Keywords: Crustacea; Decapoda; sustainable use; dams.

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Introduction

The shrimp *Macrobrachium amazonicum* (Heller, 1862) (Crustacea: Palaemonidae), commonly known in Brazil as “camarão-da-amazônia”, “camarão-canela” or “camarão-sossego”, inhabits rivers of turbid waters rich in sediments and dissolved salts as estuaries (Magalhães, 1985; Collart, 1993), and shows a wide morphological and ecological plasticity (Vergamini, Pileggi, & Mantelatto, 2011; Pileggi & Mantelatto, 2010). The presence and abundance of these shrimps in rivers influences its sympatric populations directly, affecting their reproductive cycles, feeding, and/or distribution of young and adults.

The shrimp abundance may be influenced by factors as predatory fishing for use of bait, predation by fish and birds, and modification of the environment. Such factors can influence the maintenance and balance of the population. Thus, decreases in population size are attributed to natural factors and to exploitation by humans limiting habitat availability and primary production which provides food (Fonteles Filho, 1979). Although river dams are needed for water supply and, especially, to generate energy, these structures disturb the aquatic systems and cause damages sometimes irreversible. The main effect of dams is the change from a lotic to lentic environment, with the formation of an upstream reservoir (Agostinho, Pelicice, & Gomes, 2008). The construction of dams affects the abundance and composition of species (Agostinho et al., 2008) and may decrease or even extinguish local native populations. It is also a known cause of fragmentation of aquatic environments (Dynesius & Nilsson, 1994; Roni, Hanson, & Beechie, 2008), since it modifies the influx of organic matter in the trophic webs by altering water and nutrient fluxes into the

reservoir (Agostinho et al., 2008). In a more recent study, Oliveira, Baumgartner, Gomes, Dias, and Agostinho (2018) evaluated the regulation on fish functional diversity by a dam immediately upstream from the upper Paraná River floodplain, Brazil. In the aforementioned study, the authors stated that hydroelectric power plants act as environmental filters selecting functional traits of the downstream fish fauna, generating long-lasting impacts on ecosystem. Therefore, dams affect the population dynamics of aquatic organisms upstream and downstream (Collart, 1988).

Studies of population structure contributes to the knowledge of a species biology and ecology in its natural environment and it's an important tool that also informs about the size range of individuals (Hartnoll, 1982 & Begon, Mortimer, & Thompson, 1996). Moreover, these studies facilitate the knowledge on the external and intraspecific variations that allow the establishment of *M. amazonicum* population (Pantaleão, Batista, Teodoro, & Costa, 2018). This knowledge can also support the development of future management strategies aiming at protecting the species. Montenegro, Nordi, and Marques (2001) state that shrimp of this genus can form part of the income of many fishermen in different regions, and can be sold for fishing bait, food or even with pets in aquaculture. Studies by Maciel and Valenti (2009) point to *M. amazonicum* as the freshwater decapod of greatest economic importance in the eastern South American subcontinent, and that with the expansion of the market, aquaculture may be an important alternative to supply this species. The commercial exploitation of the species was pointed out by Kutty and Valenti (2010) as a worldwide strategy. In Brazil, studies by Pantaleão et al. (2018) demonstrate that freshwater shrimp populations can reach similar sizes to coastal populations, with reduced costs, which further attracts the attention of the economy in this area.

We hypothesize that shrimp populations are negatively affected by anthropic actions such as the construction of dams and changes in the substrate. In this way, this study evaluated the abundance and population structure of *M. amazonicum* living upstream of the Água Vermelha hydroelectric dam, by sampling sites along a gradient of anthropic changes.

Material and methods

A. Sampling sites

The samplings were performed monthly, from October 2017 until March 2018, along the margins of river Rio Grande, upstream of the Água Vermelha hydroelectric power plant ("José Ermirio de Moraes"). Água Vermelha is in the border between Ouroeste, in the State of São Paulo, and Iturama, in the State of Minas Gerais (Figure 1). It was built in 1979 and all its energy production supplies the biggest electricity consumer of the country, the Southeast Region. The area was originally known as Cachoeira dos Índios fall and formed by six falls: Tombo das Andorinhas, Caldeirão do Inferno, Tombo dos Dourados, Tombo das Três Pedras, Tombo da Fumaça, and Véu de Noivas. Upstream of the main fall, several streams form the river Rio Grande. The stream Água Vermelha, meaning "red waters", is one of them, and it was named like this due to its turbid reddish waters due to the red sediments is transports due to erosion.

Six sites downstream of the dam with different environmental characteristics were chosen for the samplings of *M. amazonicum*:

Site I: Presence of large boulders placed during the construction to avoid erosion. Riparian vegetation absent. Situated 1.036 m distant from the dam, in the São Paulo's side margin.

Site II: Formed by a mix of unconsolidated and consolidated substrate. Grasses present along the margin. Located 1017 m distant from the dam, in the Minas Gerais' side margin.

Site III: With large boulders and grasses; area commonly used by fishermen. Situated 1245 m from the dam, in the Minas Gerais's side margin.

Site IV: Located in a small island with unconsolidated substrate, relatively well-preserved. The riparian vegetation is abundant and there are many floating and submerged macrophytes. Situated 2792 m from the dam.

Site V: Unconsolidated substrates, and relatively well-preserved margins, with the presence of many trees and grasses. The presence of floating and submerged macrophytes was noticed throughout the entire sampling. Situated 3490 m from the dam in the São Paulo's side margin.

Site VI: The place has characteristics indicating a spring nearby, with oily dark waters. The margins are preserved and have abundant riparian vegetation, and the substrate is unconsolidated. Floating macrophytes are also present. Situated 4368 m from the dam, in the Minas Gerais's side margin.

B. Biological sampling

The shrimps were captured once a month using sieves and traps. A sac-like sieve was used by one person and dragged for 180° three times. The traps had 100 g of grinded corn and were left in the river margins for six hours. The shrimps were placed in labeled pots containing the date, sampling mode, and site. They were cooled and, posteriorly, fixed in 70% ethanol. In the Microscopy Laboratory, the shrimps were identified according to Melo (2003), the sex was identified by male appendix viewing the second pair of pleopod, and carapace length (CL) were measured with a digital caliper. All individuals lacking secondary sexual characters were considered as juveniles. The monthly samplings were considered as replicates in the evaluation of the spatial distribution, totaling six repetitions for each variable.

C. Data analyses

The abundance data was tested by normality tests (Shapiro-Wilks, 1965 $\alpha = 0.05$) and homoscedasticity (Levene, $\alpha = 0.05$). Whenever necessary, the data were transformed into a $\log(x + 1)$ so that the test prerequisites were attending. The total abundance, and the abundance of each demographic groups was compared using the Analysis of Variance (ANOVA) followed by the Tukey test for multiple comparisons (Zar, 2010). The population structure of *M. amazonicum* was evaluated based on the frequency distribution of individuals in size classes and identification of peaks. Size class intervals were defined by the method of Sturges (1926) and for identify the peaks was used the software Peakfit v. 4.12 (Sea Solve Software Inc., 1999 – 2003).

To evaluate the sexual dimorphism and possible variations in body size depending on the site, the mean CL of the demographic groups was compared using a T-Test. The sex-ratio was compared using a Binomial Test (Wilson & Pianka, 1963) per sampling site, aiming to identify possible deviations from the expected 1:1 ratio. In all analyses the significance level was $\alpha = 0.05$ (Zar, 2010).

Results

In total, 6455 individuals were captured: 4499 females (of which 294 were breeding), 1445 males and 217 juveniles (Table 1). Both the total sex-ratio, and the sex-ratio by site were skewed towards the females (Table 1).

Table 1. Number of individuals per demographic group and sampling site and the sex-ratio of *Macrobrachium amazonicum* captured from October 2017 until March 2018 upstream of the Água Vermelha hydroelectric dam.

Demographic gruoup	Sampling sites						Total
	I	II	III	IV	V	VI	
Juveniles	2	0	102	56	54	3	217
Non-breeding females	805	829	1022	1111	547	185	4499
Breeding females	96	119	59	11	2	7	294
Males	164	399	197	477	114	94	1445
Total	1067	1347	1380	1655	717	289	6455
Sex-ratio (Total females-males)	5.5:1	2.4:1	5.5:1	2.4:1	4.9:1	2.0:1	3.3:1

The total abundance differed between all sites except sites III and IV, where the highest abundances were recorded (319 ± 4.0 and 331 ± 8.6 ind.; respectively; mean $\pm$ sd. deviation). The abundance per site decreased in the order $II > I > V > VI$ (Figure 1).

When evaluating the spatial distribution of each demographic group we noted that females were more abundant in site IV (331 ± 8.6) and less abundant in site VI (58 ± 1.4). Breeding females were more abundant in site II (23.8 ± 3.7) and less in sites IV to VI. Juveniles were more abundant in site III (20.4 ± 2.8) and less in sites I, II, and VI. Males were more abundant in site IV (95.4 ± 6.8) and less in sites V and VI (Figure 2).

The individuals were groups in 10 size classes of 2 mm amplitude. The frequency distribution indicated a bimodal pattern for males and females (Figure 3).

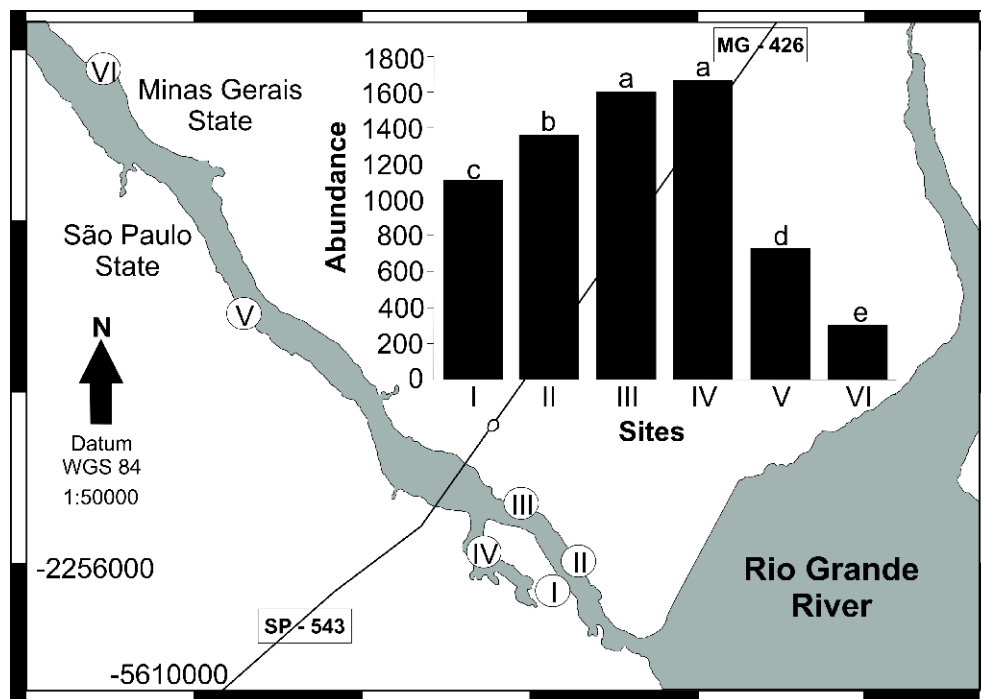


Figure 1. Map of the river Rio Grande upstream of the Água Vermelha hydroelectric dam, indicating the six sampling sites. Total abundance of *Macrobrachium amazonicum* captured from October 2017 until March 2018. Different letters indicate significant differences between sites ($p < 0.05$).

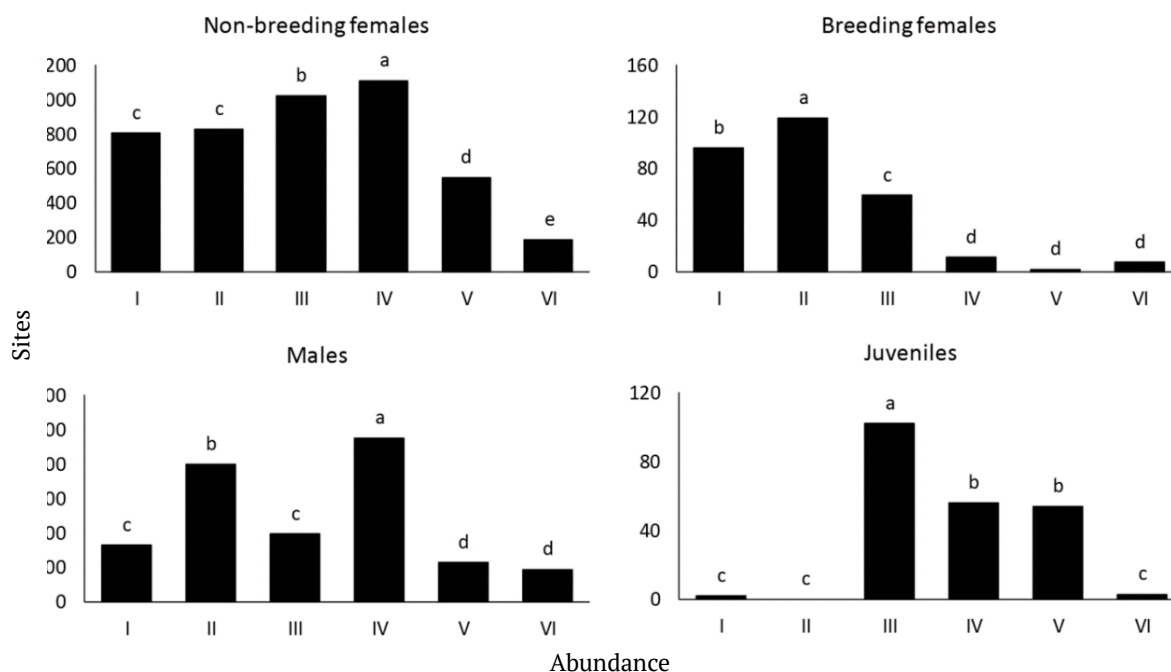


Figure 2. Abundance of demographic groups of *Macrobrachium amazonicum* captured from October 2017 until March 2018 upstream of the Água Vermelha hydroelectric dam. Different letters indicate significant differences between sites ($p < 0.05$).

Mean female size was 7.50 ± 3.47 mm CL, mean male size was 7.44 ± 3.40 mm, and mean juvenile size was 3.24 ± 1.10 mm. The smallest individual was a juvenile of 1.08 mm de CC found in site III, and the largest was a breeding female with 20 mm found in site II. There were no significant differences between the size of males and females (T-Test = 0.62, $p = 0.53$), however, a differential distribution according to size was observed: the largest individuals were found in the sites near the dam (I and II), whereas the smallest were found in site V (Figure 4A). Regarding the demographic groups, females were more abundant in sites I and II (Figure 4B), and males were evenly distributed in sites I to III and VI (Figure 4C).

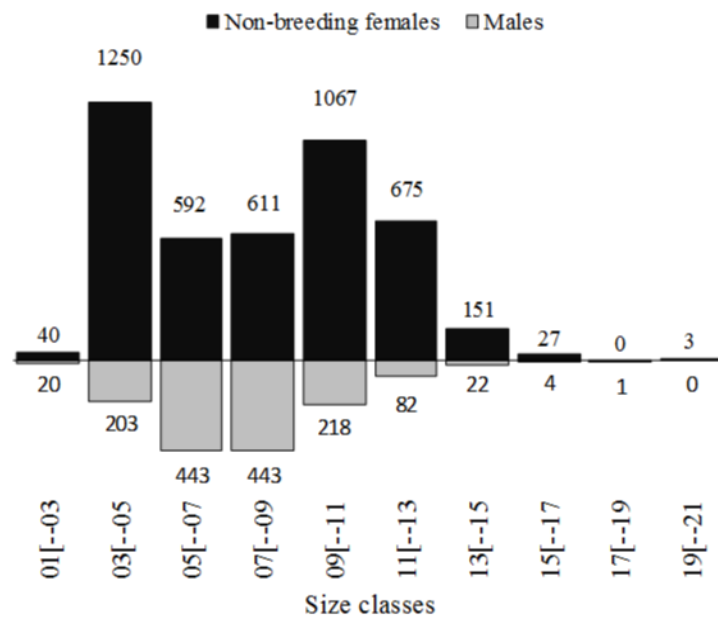


Figure 3. Size frequency distribution (carapace length) of females and males *Macrobrachium amazonicum* captured from October 2017 until March 2018, in six sites located upstream of the Água Vermelha hydroelectric dam.

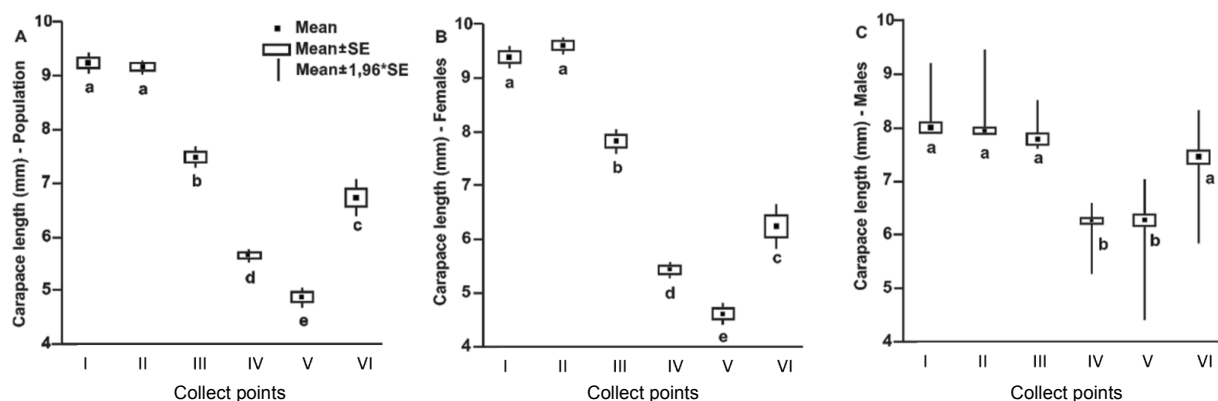


Figure 4. Mean carapace length of *Macrobrachium amazonicum*, captured from October 2017 until March 2018, in six sites located upstream of the Água Vermelha hydroelectric dam. (A) CL of population; (B) CL of females; (C) CL of males. Different letters indicate significant differences between sites ($p < 0.05$). SE = Standard Error.

Discussion

The differential occupation of habitat may be due environment variations, since demographic groups have occupation preferences based on local conditions, which are here determined by conditions modulated by the construction of a hydroelectric plant. The highest abundance of *M. amazonicum* was seen in the sites ~1200–2800 m distant from the dam (sites III and IV). This may have been caused by characteristics of these sites related to protection and food availability. Site III had a rocky substrate with countless crevices where the shrimps could hide and protect against predators. In site IV, the low hydrodynamism possibly allowed a longer foraging time in the abundant macrophytes with a lower energy demand. According to Junk (1973), macrophyte roots serve as shelters and provide a constant food supply. Merritt and Lawson (1992) considered benthonic macroinvertebrates such as *M. amazonicum* as shredders, the main organisms responsible for the transformation of particulate organic matter into smaller particles. In this way, the input of plant material from the riparian forest into the rivers supplies more food.

Breeding females were present in greater abundance at sites II, I and III, respectively. When comparing this distribution with the characteristics of the sampled area, it is possible to infer that such females seek regions with the presence of microhabitats in search of protection and food. The site II, for presenting grasses and small rocks, offered better conditions for the establishment of breeding females. The site I consisted only of large rocky boulders, which resulted in less abundance for this group. Despite the fact that site III presents conditions similar to site I, the formation of a small bay conditions the proliferation of fish

that prefer still water, which may have caused the reduction of embryonic females in the place. The near absence of this group at sites IV, V and VI can be justified by the larval dispersal event, which will be discussed later.

The lowest abundance was seen in the farthest site, where the affluent is present, and the water has an oily aspect. Fishermen that commonly use this site affirm that it is a good fish spot due to the presence of a high fish diversity, including species such as *Leporinus macrocephalus* Garavello and Britski, 1988 “piaçu”, *Hoplias* sp Gill, 1903 “traíras”, and *Cichla ocellaris* Bloch and Schneider, 1801 “tucunarés (pers. comm.). In the study by Souza, Barros, and Braun (1996) the authors affirm that the genus *Macrobrachium* may be predated by “traíras” (*Hoplias malabaricus* Bloch, 1794), whose diet is composed of smaller fishes and crustaceans (Gama & Halboth, 2003). Moreover, Lima, Silva, and Lira (2013) mentioned that breeding females of *Macrobrachium jelskii* (Miers, 1877) may be predated by fishes as *Hoplias malabaricus*. The varied fish species recorded in the region are omnivores and carnivores, and their presence may be one of the factors determining the habitat use by *M. amazonicum*. Moreover, Mattos and Oshiro (2009) reported in Australia that a bird species of order Pelecaniformes, *Platalea regia* (Gold, 1838), known as “colhereiro-real”, is the main predator of *Macrobrachium intermedium* (Stimpson, 1860). In our study region, many existing bird species could prey on *M. amazonicum*, including birds of Pelecaniformes.

The largest males, females, and breeding females were found in the sites near the dam, while the smallest we found in the farthest sites. During the reproductive cycle individuals may disperse and colonize different habitats, as larvae, juveniles, and adults prefer different microhabitats where they can obtain shelter and food (Silva, 2014). This apparent different habitat choice depending on the demographic group may help decrease intraspecific competition and facilitate the maintenance of the population in the area. This competition could also be noted during the use of different sampling methods: the sieve captures more small individuals, while the traps easily attract the largest ones due to the availability of food (as suggested by Pantaleão et al., 2018). Also, in the traps, the presence of large individuals hampers the entrance of the smaller ones.

According to Coelho and Santos (1993), the distribution pattern of males and females may be related to reproduction. The largest individuals possibly remain near the dam to reproduce and facilitate the larval dispersion downstream after hatching; in addition, near the dam there is greater movement of water, which can possibly increase oxygen concentrations. Olivier and Bauer (2011) reported a higher frequency of *Macrobrachium ohione* (S. I. Smith, 1874) breeding females upstream of the river Atchafalaya (Louisiana, USA), corroborating our results. *Macrobrachium carcinus* (Linnaeus, 1758) and *Macrobrachium acanthurus* (Wiegmann, 1836) were seen using the fish lifts of a hydroelectric dam to migrate (Pompeu & Martinez, 2003). This reproductive behavior may indicate a strategy for higher larval dispersion, such as the one described in the present study. Apparently, the differences in spatial distribution depending on the demographic group, aiming at enhancing larval dispersion and the use of habitats more suitable to each life cycle phase, is a common strategy of crustaceans. The differential habitat use was also reported in the marine shrimps *Rimapenaeus constrictus* (Costa & Fransozo, 2004), *Pleoticus muelleri* (Bate, 1888) (Costa, Fransozo, & Pinheiro, 2004), *Xiphopenaeus kroyeri* (Heller, 1862) (Costa, Fransozo, Freire, & Castilho, 2007), *Farfantepenaeus* spp. (Costa et al., 2004), in the swimming crabs *Callinectes ornatus* Ordway, 1968 (Andrade et al., 2013) *Callinectes danae* Smith, 1869 (Andrade et al., 2015), and in the crab *Eriphia gonagra* (Fabricius, 1781) (Andrade, Góes, Fransozo, Alves, Teixeira, & Fransozo, 2014b).

According to Bialecki, Nakatani, Baumgartner, and Bond-Buckup (1997), *M. amazonicum* has a fast development and broad colonization, which suggests a wide adaptive plasticity to diverse environments (Vergamini et al., 2011). Although there was no measurement of the physical-chemical parameters at the collection points of this study, our sites differed conspicuously (see Material and Methods), and this may have caused the differences in abundance. Local conditions may affect the population structure much more strongly than the overall conditions of the area, affecting the abundance and size of individuals (Andrade, Bertini, Fransozo, Teixeira, Alves, Fransozo, & NEBECC (Crustacean Biology, Ecology and Culture Study Group), 2014a).

According to our results, males and females did not differ in size. However, Shakuntala (1977) affirms that sexual dimorphism in size is a characteristic of carideans and that females always reach larger sizes, whereas Valenti (1987) affirms that in the genus *Macrobrachium* the males are larger because females molt before and after hatching. During these molts the growth rate decreases as the energy reserves are used for

gonadal maturation (Silva, Fréudou, & Rosa Filho, 2007). These inconsistencies may result from genetic variations between populations and/or due to environmental conditions that stimulated or inhibited the growth of each sex (Alves et al., 2012).

The size range seen in our sampling also differed from previous studies. Freire, Marques, and Silva (2012), studied *M. amazonicum* in the northeast of the State of Pará reported a size range of 5.0–32.5 mm CL. In the State of Tocantins, the largest individual had 28 mm (Collart, 1988). These differences may be explained by the environmental conditions of our study sites (Hartnoll, 1982). Costa e Silva (2014) affirms that individuals from freshwater species inhabiting large rivers are generally larger, due to an effect of the river flow on the development of the animals (Costa e Silva, Cunha, Mossolin & Jacobucci 2014).

The sex-ratio was always skewed towards the females. Regarding *M. amazonicum*, Montoya (2003) reported a sex-ratio of two females to each male in the Orinoco delta, in the east of Venezuela, and Silva et al. (2007) reported a sex-ratio similar to the one seen here, of three females to one male, in a population from Ilha de Combú (Belém, Pará).

With that, the hypothesis that the Agua Vermelha hydroelectric power plant could be affecting the population of *M. amazonicum* negatively was rejected since we observed a high abundance in the sites closer to the dam. However, we believe that local conditions and the species' maintenance strategies, and not the dam itself, were the main determinants of this pattern.

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