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Population structure of freshwater prawn *Macrobrachium amazonicum* (Crustacea, Palaemonidae) in two regions of the Amazon River, Brazil

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ABSTRACT

Introduction: *Macrobrachium amazonicum* is a species of shrimp native to South America, widely distributed and exploited by artisanal fishermen in the North of Brazil.
Objective: This study aimed to analyze the population structure of *M. amazonicum*, with an emphasis on sex ratio, frequency distribution of male and female size, also considering the rainy and dry period in the study areas.
Methods: For this, monthly collections were carried out from May 2017 to April 2018 with the help of "matapis" in two locations, Mazagão and Ilha das Marrecas.
Results: A total of 6 796 (4 163 females and 2 633 males) were captured, with a monthly average of 531.66 specimens. The sex ratio in both areas was favorable to females with 1.32♀ : 1♂ ($x^2 = 76.58$, $p < 0.001$) in Mazagão and 2.34♀ : 1♂ ($x^2 = 394.26$, $p < 0.001$) in the Ilha das Marrecas. In both Mazagão and Ilha das Marrecas, abundance was strongly related to precipitation.
Conclusions: The shrimps of Ilha das Marrecas were longer than those caught in Mazagão. Despite this fishing pressure in Mazagão, the areas proved to be favorable for the growth of the species.

Keywords: morphometry; sex ratio; white water Amazon shrimp; estuary; river.

RESUMEN

Estructura poblacional del camarón de agua dulce *Macrobrachium amazonicum* (Crustacea, Palaemonidae) en dos regiones del río Amazonas, Brasil

Introducción: *Macrobrachium amazonicum* es una especie de camarón nativa de América del Sur, ampliamente distribuida y explotada por pescadores artesanales en el Norte de Brasil.
Objetivo: Este estudio tuvo como objetivo analizar la estructura poblacional de *M. amazonicum*, con énfasis en la proporción de sexos, distribución de frecuencias de tallas de machos y hembras, considerando también el período lluvioso y seco en las áreas de estudio.
Métodos: Para ello, se realizaron colectas mensuales de mayo de 2017 a abril de 2018 con la ayuda de «matapis» en dos localidades, Mazagão e Ilha das Marrecas.

Resultados: Se capturaron un total de 6 796 (4 163 hembras y 2 633 machos), con una media mensual de 531.66 ejemplares. La proporción de sexos en ambas áreas fue favorable a las hembras con 1.32♀ : 1♂ (x^2 = 76.58, p < 0.001) en Mazagão y 2.34♀ : 1♂ (x^2 = 394.26, p < 0.001) en la Ilha das Marrecas. Tanto en Mazagão como en Ilha das Marrecas, la abundancia estuvo fuertemente relacionada con la precipitación.
Conclusiones: Los camarones de Ilha das Marrecas eran más largos que los capturados en Mazagão. A pesar de esta presión pesquera en Mazagão, las zonas resultaron favorables para el crecimiento de la especie.

Palabras clave: morfometría; proporción de sexos; camarón blanco del Amazonas; estuario; río.

INTRODUCTION

The understanding of crustacean population variability in different environments provides information on the habits and characteristics of the species life cycles and how these are related to the environment, so permitting an understanding of the ecological stability of group members, including shrimp (infraorder Caridea) (Bentes et al., 2016). Such information provides the basic underpinning for management of shrimp aquaculture. Information on the size distribution of male and female specimens, sex ratio, spatial distribution of individuals and population age structure can, for example, be used to explain seasonal variations in size, reproductive strategies and productive potential (Silva et al., 2007; Silva et al., 2019).

In this context, population studies on *Macrobrachium amazonicum* (Heller, 1862) are especially important, as the species is both scientifically and commercially important in north and Northeastern Brazil (Alcântara & Kato, 2016; Costa et al., 2021; Lima et al., 2016; Melo et al., 2022; Ramos et al., 2016). The species is commercially exploited in the states of Amazonas, Pará and Amapá by artisanal fishing and indigenous populations (Bentes et al., 2016; Lima et al., 2014). In general, *M. amazonicum* populations are characterized by variations in the population structure, and there may be differences in the distribution of individuals in all months of the year (Sampaio et al., 2007; Silva et al., 2019). However, in the Amazon region fishing pressures on the species may lead led to unsustainable exploitation (Bentes et al., 2014; Freire et al., 2012a; Lima et al., 2014; Lucena-Frédou et al., 2010).

The knowledge of the proportions of the sexes, sizes and growth stages is important for effective management and to guarantee sustainable use of *M. amazonicum* in the Amazon region. Accordingly, the current study was performed to examine the population structure of *M. amazonicum* with emphasis on sex ratio and size frequency distribution in the regions of the Amazon river mouth and lower reaches.

MATERIAL AND METHODS

Study area and rainfall data: Samples of *M. amazonicum* were collected monthly from May 2017 to April 2010, on the Mazagão River (00°15'39.9"S & 051°20' 42.3'W), located at the mouth of the Amazon River, state of Amapá, and in the Ilha das Marrecas complex on the lower Amazon River (02°12'19.3"S & 054°46' 17.9'W), state of Pará (Fig. 1). The shrimps of the two study sites were pooled for analysis because the areas studied shown relatively different in their physiography. The Mazagão River shows various drainage channels, with varying sizes and depths and daily influence of the tide, allowing the daily flooding and the formation of a wide diversity of microhabitats. The vegetation is typical of the "várzea Amazon", dense with large and wide bands of macrophytes along the river margin.

In the Ilha das Marrecas, the vegetation is similar to that observed in the Mazagão River, with dense, large, and wide bands of macrophytes along the Amazon riverbed. However, thus hydrodynamics is different. In Ilha das Marrecas, not the daily influence of the tide only annual variations in the river depth due to the common floods in the winter period. These

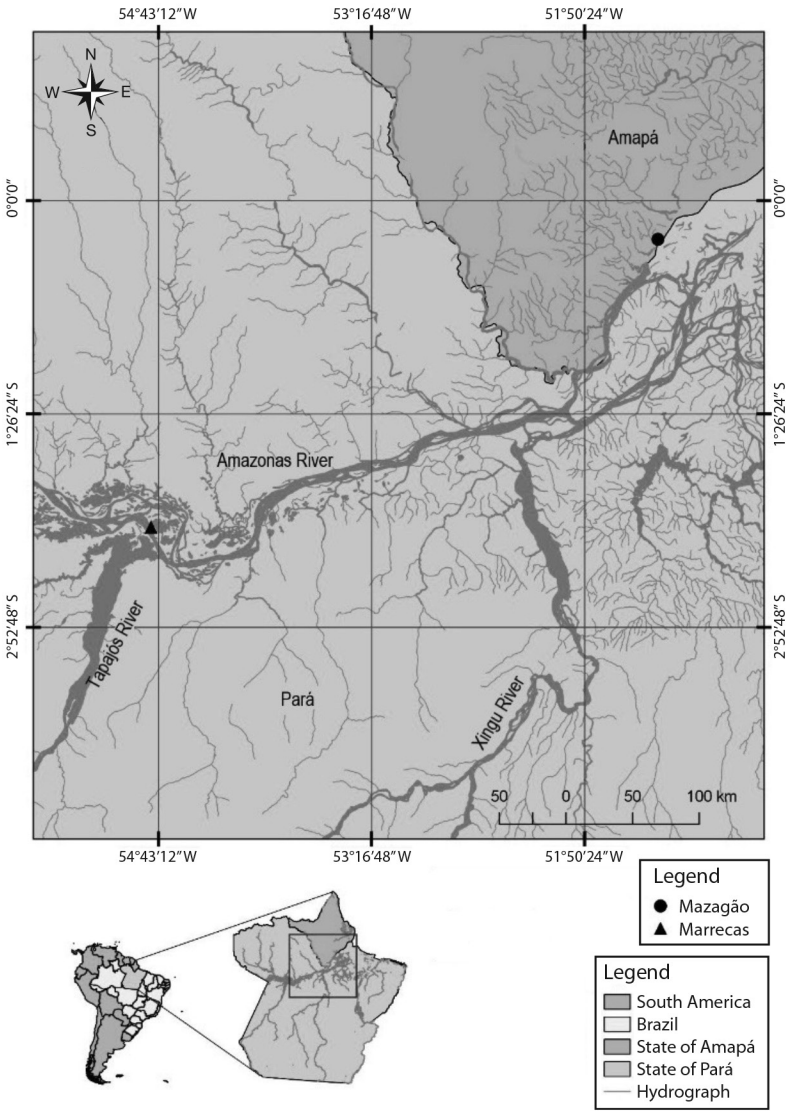

Fig. 1. The location of *Macrobrachium amazonicum* captures areas in the mouth and lower Amazon between May 2017 and April 2018, and July 2021 to May. The black circle (●) represents Mazagão, while the green triangle (▲) represents Marrecas Island.

natural floods cause cycles of erosion, transportation and deposition of sediments, with systematic annual morphological modification of the riverbed (Farias & Carneiro, 2012).

Both areas have a humid Equatorial climate, with two seasonal periods marked by a rainy period from December to June and a less rainy (dry) period from July to November. To assist the study with updated data on local seasonality, monthly data on rainfall were obtained from the website of the Instituto Nacional de Meteorologia (INMET, 2021).

Shrimp collection: For the collection of the shrimp 20 traps locally known as "matapis" were used. Traps were set and submerged over

a single nocturnal tidal cycle (12 hours). All captures occurred at daybreak. They were then recovered one at a time and the contents were removed, placed in plastic bags, labeled, stored on crushed ice in a cooler, and transported to the laboratory.

Shrimp Analysis: In the laboratory, shrimps were identified, sexed and submitted to biometrics. Taxonomic identification following the taxonomic keys of Melo et al. (2003). Sex was verified by the presence of masculine appendix on the second pleopod. To biometrics standard length (SL-linear distance from the base of ocular orbit to the base of the telson) and total wet mass (TM) of shrimps a digital caliper (0.01 mm precision) and a digital scale (0.01 g), were used to measure, respectively. Individuals with measures below the smallest identifiable male will be considered sexually undifferentiated, while shrimps with sizes below the smallest female egg will be considered juveniles (Lima et al., 2014).

The monthly rainfall data of each region was obtained at the data of base the INMET (2021).

Data analysis: The statistical analysis of the data was performed with the aid of the BioEstat 5.0® software (Ayres et al., 2007). Normality and homoscedasticity of the variances were tested with Shapiro-Wilk and Bartlett's tests, respectively.

The sex ration was determined per month in each collection site using the chi-square test (x^2, $\alpha = 0.05$) according to Zar (1999). The t-test was applied to verify differences sex ration between collection sites. Kruskall-Wallis test was applied to verify differences between standard length of males and females during the studied period. The t-test was applied to verify differences regarding standard length between sex and collection sites. All analysis p-value equal or less than 0.05 were chosen to indicate statistical significance. To verify if there is a relationship between rainfall and the abundance of prawn by area, one regression analysis was performed (Zar, 1999).

RESULTS

A total of 6 796 shrimps were caught, of which 4 132 (60.8 %) were in Mazagão and 2 664 (39.2 %) in Ilha das Marrecas. The total number of shrimps caught in Mazagão was higher than in Ilha das Marrecas ($p < 0.05$) in most study months, except in June and April 2018 (Fig. 2). In general, the *M. amazonicum* catch was higher during the period with less rain (July to October), particularly for adult shrimps (Fig. 2, Fig. 3).

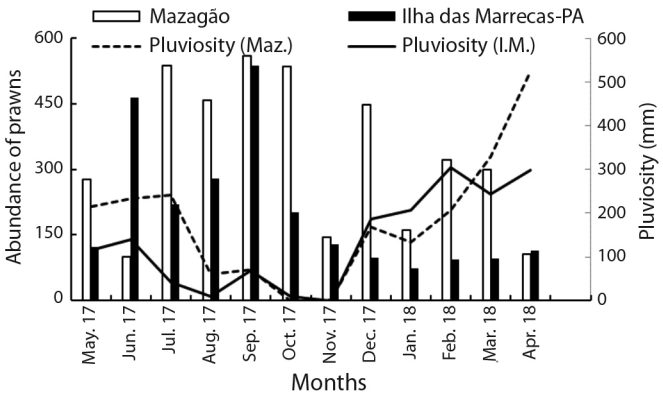

Fig. 2. Abundance of *M. amazonicum* (Heller, 1862) collected between May 2017 and Apr 2018 in the mouth of Mazagão River-AP and Ilha das Marrecas-PA; and their relationship with rainfall.

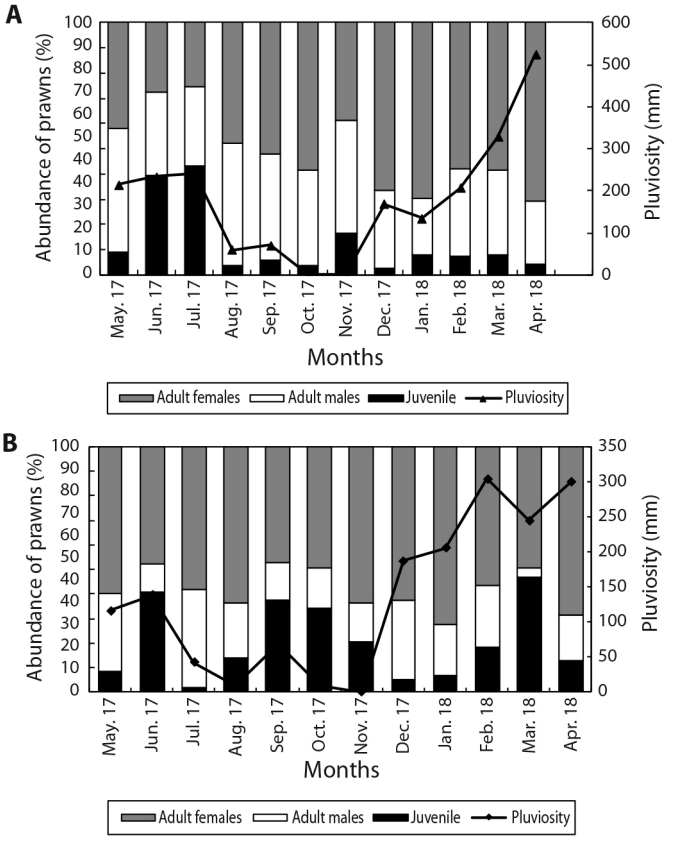

Fig. 3. Monthly absolute frequency distribution of juvenile, adult males and adult females of *M. amazonicum* (Heller, 1862) collected between May 2017 and Apr 2018. **A.** in the mouth of Mazagão River-AP. **B.** in Ilha das Marrecas-PA.

Chi-square test showed that the sex ratio was significantly different from 1:1 in Ilha das Marrecas ($x^2 = 394.26$, $p < 0.001$) and Mazagão ($x^2 = 76.58$, $p < 0.001$), being 2.34♀ : 1♂ and 1.32♀ : 1♂ respectively. In Mazagão, *M. amazonicum* showed significant differences in relation to the expected sex ratio except in the months, May, July, August and September of 2017 and January of 2018. In contrast, in Ilha das Marrecas, sex ratio differences were observed in all collection months (Table 1).

In both study areas monthly distribution of adult juveniles, males, and females showed season variation (Fig. 3A, Fig. 3B). In Mazagão, numerical dominance of male and adult female shrimps alternated in both seasons. Adult male shrimps dominant in May, July, August, September, and adult female shrimps from December to April (rainy season). While in Ilha das Marrecas, adult female shrimps were not only more abundant than the adult males in the rainy season (January to April), but also across most of the period with little rain (July to December).

Juvenile shrimps were found in all months of the year, in both regions, with a recruitment peak in June and July (Mazagão) and June, September, October and March (Marrecas), with juveniles comprising between 35 % and 45 % of the catch (Fig. 3A, Fig. 3B).

In Mazagão, male shrimps of the length class 43.4 mm to 49.4 mm were commonest while most female shrimps were between 49.4 mm and 55.4 mm. In Ilha das Marrecas, male

Table 1

Chi-square values and sex ratio of *M amazonicum* sampled in Mazagão and Ilha das Marrecas between May 2017 and April 2018.

Months	Mazagão				Ilha das Marrecas				Group Areas			
	♀	♂	x²	Ratio	♀	♂	x²	Ratio	♀	♂	x²	Ratio
may/17	131	136	2.63	0.82:1	91	32	28.30	2.8:1*	216	184	2.6	1.17:1
jun/17	143	33	0.49	1.14:1*	350	115	118.76	3.04:1*	404	162	103.5	2.49:1*
jul/17	153	172	1.80	0.88:1	130	90	7.27	1.44:1*	413	342	6.7	1.20:1*
aug/17	220	221	0.08	0.97:1	172	108	14.63	1.59:1*	398	340	4.6	1.17:1*
sep/17	290	236	7.81	1.26:1*	354	184	53.72	1.92:1*	666	430	50.8	1.54:1*
oct/17	456	320	21.40	1.5:1*	152	50	51.50	3.04:1*	473	264	59.3	1.79:1*
nov/17	220	50	11.11	1.76:1*	90	38	21.31	2.36:1*	182	90	31.1	2.02:1*
dec/17	299	138	64.51	2.23:1*	79	19	36.73	4.15:1*	388	158	96.9	2.45:1*
jan/18	82	59	2.99	1.31:1	58	15	25.33	3.86:1*	150	85	18.0	1.76:1*
feb/18	186	112	17.52	1.60:1*	67	27	17.02	2.48:1*	265	150	31.9	1.76:1*
mar/18	176	101	17.28	1.63:1*	74	21	29.57	2.48:1*	260	135	39.6	1.92:1*
apr/18	147	51	0.45	087:1*	88	27	32.36	3.25:1*	138	84	13.1	1.64:1*

*Significant differences from the chi-square test, $p < 0.05$.

Table 2

Frequency distribution of shrimps *M. amazonicum* in size classes (CP), collected between May 2017 and April 2018 in Mazagão-AP and ilha das Marrecas.

Classe (CP, mm)	Mazagão				Ilha Marrecas			
	Adult Males	Adult Females	Juveniles Males	Juveniles Females	Adult Males	Adult Females	Juveniles Males	Juveniles Females
31.4-37.4	-	-	70	123	-	-	70	125
37.4-43.4	276	345		-	-	-	64	110
43.4-49.4	469	361	-	-	25	165	-	-
49.4-55.4	237	601	-	-	107	638	-	-
55.4-61.4	303	529	-	-	125	499	-	-
61.4-67.4	202	315	-	-	206	235	-	-
67.4-73.4	112	15	-	-	50	59	-	-
73.4-79.4	111	2	-	-	51	56	-	-
79.4-85.4	7	5	-	-	15	18	-	-
85.4-91.4	10	14	-	-	12	11	-	-
91.4-97.4	7	10	-	-	10	6	-	-
97.4-03.4	0	8	-	-	5	2	-	-
Total	1 734	2 205	70	123	606	1 689	134	235

and female shrimps were most common in the length classes 61.4 mm to 67.4 mm and 49.5 mm to 55.4 mm, respectively (Table 2). Analysis of variance showed significant differences in the standard lengths of males, females and total shrimp lengths between the sites, but not between collection months (Fig. 4).

Males captured in Ilha das Marrecas had a higher mean length than those captured in Mazagão in May and October 2017 and February and April 2018 (Fig. 4A). Additionally, females caught in Marrecas had longer mean lengths than those caught in Mazagão between June and September 2017 and March and April

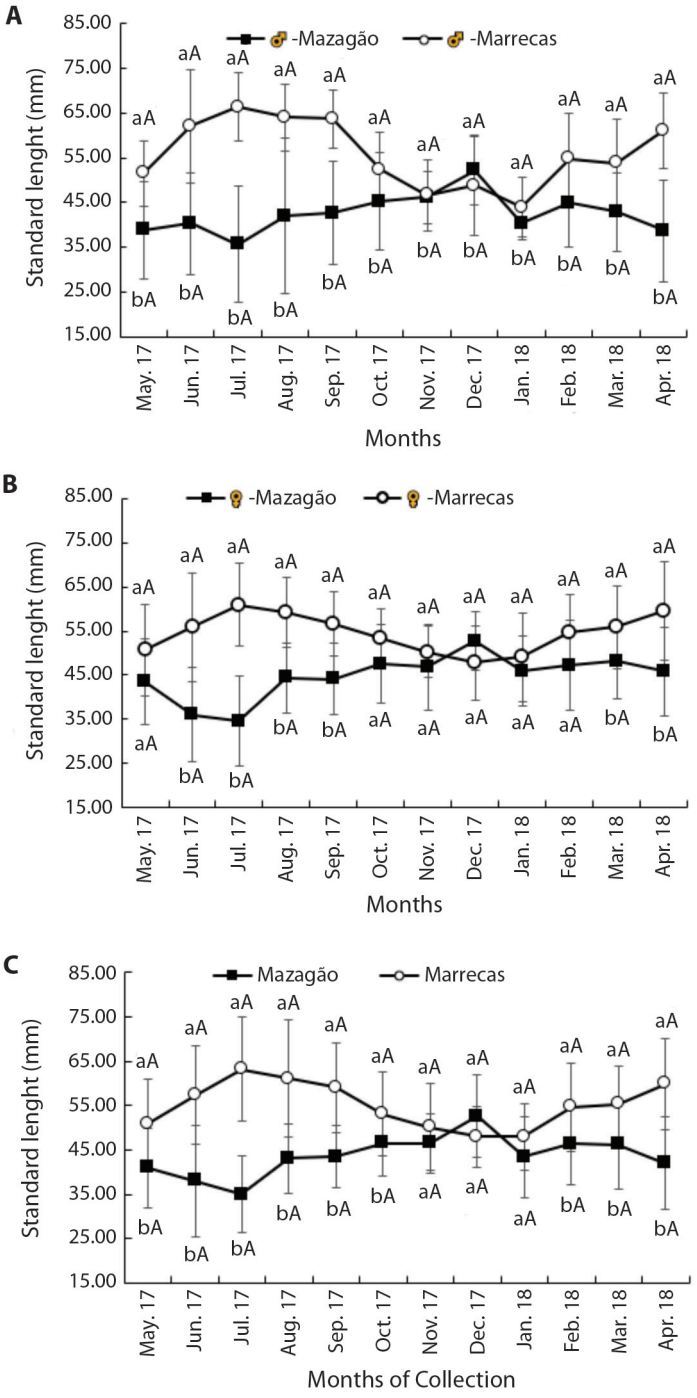

Fig. 4. Monthly variation of standard length between males, females and grouped sex of *M. amazonicum* collected in the Mazagão River-AP and Ilha das Marrecas -PA, between May 2017 and Apr 2018. **A.** Males. **B.** Females and **C.** Grouped sex. Different lower letters represent significant differences between the collection sites, while different upper-case letters represent differences between the months.

2018 (Fig. 4B). In the months of November and December 2017 and January 2018 (Fig. 4C), mean length for all shrimps captured in Mazagão exceeded those from Ilha das Marrecas.

DISCUSSION

Macrobrachium amazonicum was more abundant in Mazagão than in Ilha das Marrecas, except in the months of June 2017 and April 2018. In general, the coastal areas of the Amazon show a greater abundance of this species compared to more continental sites (Lima et al., 2014; Meireles et al., 2013). This difference in abundance may be linked to the amount of suspended organic matter and nutrients available. This is a consequence of differences in the intensity of tidal activity and bioturbation, which favor the development of a remarkable productivity of micro invertebrates, algae and fine particulate organic matter in more coastal areas. Another aspect is the proximity of estuarine areas to the oceanic itself. *Macrobrachium amazonicum* is an eurihaline species, tolerating a wide range of salinity, but with larva which develop best in waters with a particular salinity concentration, as shown by a number of laboratory studies (Araujo & Valenti, 2010; Perroca et al., 2022; Soeiro et al., 2016; Sterzelecki et al., 2021). Despite tolerating a wide concentration of salinity as adults, there are changes in the larval stages of this species, which include morphological changes in the gills and expression of the sodium and potassium ATPase pump (Na+, K+ ATPase-NKA), which reduce larval survival at low salinities (Boudour-Boucheker et al., 2013). Thus, *M. amazonicum* populations in estuarine areas have better conditions to complete their larval development than populations from more continental sites.

Differences in abundance between seasonal periods is a particular trend of each species in the genus *Macrobrachium*: *M. brasiliense* (Heller, 1862) (Mantelatto & Barbosa, 2005), *M. macrobrachion* (Herklots, 1851) and *M. vollenhovenii* (Herklots, 1857) (Lawal-Are & Owolabi, 2012) all display greater rainy season abundance, unlike *M. iheringi* (Ortmann, 1897), *M. ohione* (Smith, 1874) (Truesdale & Mermilliod, 1979), *M. tenellum* (Smith, 1871) (Román-Contreras, 1979), *M. olfersi* (Wiegmann, 1836) (Mossolin & Bueno, 2003) and *M. amazonicum*, which are clearly more abundant during the less rainy season.

Data for the current study followed this pattern, so that in both Mazagão and Ilha das Marrecas, abundance was strongly related to precipitation, with highest catches during the less rainy season (July to October). These results corroborate data from other parts of the Amazon which show reproductive peaks of *M. amazonicum* coinciding with the rainy season period (Lima et al., 2014; Melo et al., 2022), and the recruitment period coinciding with the dry season (Bentes et al., 2016; Costa et al., 2016; Costa et al., 2021).

In the current study, a predominance of females was observed at both study sites. This bias seems to be common in the genus *Macrobrachium* (dos Santos-Antunes & Oshiro, 2004; Fransozo et al., 2004; Meireles et al., 2013; Melo et al., 2022). It has been reported for estuarine and coastal populations of *M. amazonicum* in the Amazon region (Freire et al., 2012b; Lima et al., 2014; Montoya, 2003; Sampaio et al., 2007; Silva et al., 2007). However, an excess of males (Mantel & Dundgeon, 2005) and equal male : female ratios (Mattos & Oshiro, 2009) have also been observed for the genus.

Although a predominance of females was common, the monthly mean sex ratio values in favor of females was higher in Marrecas than in Mazagão, while in some months no significant differences were observed. In crustaceans deviations in the sex ratio may be a consequence of many factors, including between-sex differences in size, mortality, and hatching rates. But factors such as development rates, dispersion, reproduction, differential migration, environmental conditions, geographic characteristics and anthropogenic interference may also be influential (Botelho et al., 2001; Lima et al., 2014; Perroca et al., 2022; Sterzelecki et al., 2021). As the environmental characteristics and availability of nutritional resources are similar between the two study areas, it is likely that the

greater abundance of females in Marrecas is related to the reproductive strategy adopted by *M. amazonicum* populations in each region. In Marrecas, there is a clear reduction in the availability of salinity and there is little tidal influence, thus an increase the number of females there means that a larger number of larvae are available to close their cycle and increase the availability of juveniles for dispersion, so maintaining the population (Bentes et al., 2016; Silva et al., 2019).

The unplanned, unmanaged and intensive exploitation of these shrimps is another factor that may be related to sex ratio changes, as observed in populations of *M. amazonicum* from the island of Combú in Pará State, Brazil (Lucena-Frédou et al., 2010; Silva et al., 2002). However, in Ilha das Marrecas, where fishing pressure is currently very low compared to Mazagão, the sex-ratio distortion cannot be attributed to this fact. Instead, it is likely to be associated with the fact that the *M. amazonicum* population on the lower Rio Tocantins (State of Pará), became isolated after the construction of a dam. This appears to have strongly affected the shrimps, resulting in a reduction in the average size of the captured specimens and a doubling of sex ratio in favor of females (Odinetz-Collart, 1991).

For the biometric variables, young and adult shrimp caught in Ilha das Marrecas had a greater standard length than the those caught in Mazagão, except in November and December 2017 and January 2018 (Fig. 4C). As climatic, environmental and nutritional conditions are similar between Ilha de Marrecas and Mazagão, this difference is most likely explained by fishing pressure, which is substantially higher in the region of the mouth at the Amazon River where Mazagão occurs than in the lower river Amazonas, where the Ilha das Marrecas lies. As observed previously, high fishing pressure can alter *M. amazonicum* population structure and dynamics, especially the size and sexual proportion (Lucena-Frédou et al., 2010; Melo et al., 2022; Silva et al., 2002). Comparing our results with other studies, it appears that the average size of the shrimp caught in Mazagão is similar to that reported in studies at other estuarine sites in the Amazon region (Bentes et al., 2011; Costa et al., 2021; Silva et al., 2002; Silva et al., 2007), while size of shrimp caught in Ilha das Marrecas were similar in that of those caught in more coastal areas (Borges, 2003) and in reservoir areas such as Rômulo Campos in Bahia State, Brazil (Costa et al., 2016).

For recruitment it was apparent that young shrimps constantly entered the population every month. However, there were months when these individuals were more abundant (June and July in Mazagão; June, September, October and March in Ilha das Marrecas). The presence of juvenile shrimps throughout the year in both study areas suggests that *M. amazonicum* has continuous recruitment. A continuous pattern of recruitment was also observed in estuarine and continental populations in Ilha de Combu in Pará state (Lucena-Frédou et al., 2010), in Guajará Bay, Pará (Bentes et al., 2011), in the reservoir of the Miranda hydroelectric power-plant, Rio Araguari in Minas Gerais state (Silva, 2014). The continuous recruitment of juveniles at the two study sites likely reflects the reproductive strategy of *M. amazonicum* adopted in each region. In both areas, a predominance of females was observed, with continuous reproduction, reflecting the constant recruitment of youngsters (Rocha et al., 2023; Ventura et al., 2019).

In the Amazon region, shrimps are mainly exploited with traps popularly known as *matapís* (Costa et al., 2016). Such traps are usually produced with jupati palm (*Raphia vinifer*) splint, with have very small gaps between the splints (three millimeters on average) that allow the capture of shrimp in the immature stages or early in maturation (Lima, 2014). This fact was shown in Mazagão and in Ilha de Marrecas, where shrimps below the size at first maturation were captured in all months of the study. Evidence of similar current fishing impacts on the *M. amazonicum* population was reported from the ilha de Combú, Pará state (Silva et al., 2007), and at the mouth of the Amazon River in the state of Amapá (Lima, 2014). At both sites matapi fishing is affecting local *M. amazonicum*

populations (Lucena-Frédou et al., 2010), and negatively implicating the natural stocks of the species in the region.

Based on our results of juvenile-stage capture and data presented by Camargo et al. (2009), it is highly likely that the splint-separation distance of 2.0 mm to 5.0 mm currently used by artisanal fishermen in the Amazon region is not appropriate. For *M. amazonicum* the length at first maturation (between 45.0 mm and 60.0 mm) reported by Guest (1979), Moraes-Riodades and Valenti (2002), Sampaio et al. (2007), Lima et al. (2014) and Bentes et al. (2014) is lower than those found in Mazagão and Ilha das Marrecas, indicating that shrimp fishing in these areas has not yet reached the level of exploitation reported at other sites.

Given the results of the current study, it is recommended that the minimum spacing of 1 cm between the matapís splints be adjusted downwards, a proposal already made for *M. amazonicum* by both Camargo et al. (2009) and Lima (2014). In an attempt to reduce fishing pressure, studies such as Camargo et al. (2009) and Lima (2014) have suggested changes in traps and capture strategies. In addition to changing in the distance between matapí splints, these authors suggest that the local and state authorities, who police the environment, implement and monitor an active fishery management policy for the species. This should include setting the size between 60 and 70 mm (first maturation) as the lower catch size limit for the species in the estuary region. For Mazagão and Ilha das Marrecas, we can see that such catch limits would also be appropriate. Such a measure would result in a considerable increase in the number of breeding specimens and, consequently, an increase in the size of shrimp caught later, generating more income for fishermen and merchants, as well as greater satisfaction for consumers, who will be able to purchase larger products, which are more attractive to consumers.

M. amazonicum showed variations in the pattern of population structure in Mazagão and in the Ilha das Marrecas. In Mazagão a greater abundance of specimens was observed. In relation to females, in Mazagão and in the Ilha das Marrecas, they were significantly larger and heavier than males, denoting differentiated metabolism, probably due to reproduction, in addition, a predominance of females and variation between the average length was observed indicating that the populations of Mazagão and Ilha das Marrecas are distinct. In both areas *M. amazonicum* showed a reproductive peak closely related to the rainy season, however, the species reproduction occurs continuously throughout the year.

Ethical statement: The authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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