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Original Article

Population biology of the freshwater shrimp *Atya scabra* (Leach, 1816) (Crustacea: Decapoda) in São Francisco River, Brazil: evidence from a population at risk of extinction

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Abstract

Considering the environmental impacts to rivers caused by the exploitation of water resources and the consequences of these impacts upon fauna, the objective of this study was to evaluate the population biology of the shrimp *Atya scabra* (Leach, 1816) in the final stretch of the major river of South America. This species was assessed as "Near Threatened" in the red book of Brazilian crustaceans. Specimens were sampled monthly from February 2015 to January 2016 in a region of the lower São Francisco River, Brazil. A total of 233 individuals of *A. scabra* were collected, including 120 males and 113 females (71 non-ovigerous and 42 ovigerous). *Atya scabra* abundance was higher when water flow values increased. A decrease in abundance was observed over the one year of sampling, indicating a decline of about 90 % in this population in this region of the São Francisco River. We suggest that this decline was caused by the reduction of water flow in the São Francisco River, due to a policy that authorized retaining more water behind dams and releasing less water into the river in April and June 2015. In light of this, other studies should monitor the population dynamics of this species, while legislative actions are also needed to protect this fragile ecosystem.

Keywords

Atyidae, conservation, Neotropical region, preservation, South America

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Introduction

Habitat loss has negative impacts on species richness, population abundance, and genetic diversity (Laurence *et al.*, 2002; Aguilar *et al.*, 2008) and rivers are some of the ecosystems most negatively impacted worldwide (Strayer and Dudgeon, 2010; Vörösmarty *et al.*, 2010). Human actions, such as the construction of dams for energy generation and the deviation of water to supply irrigation systems for extensive agriculture, result in habitat loss for many species living in these rivers (De Grave *et al.*, 2015). Thus, natural characteristics, such as flow volume and velocity can directly or indirectly have an impact on the fauna that inhabit these rivers, some of which can be under the threat of extinction (De Grave *et al.*, 2015). Estimates suggest that at least 10,000–20,000 freshwater species are at risk of extinction (Strayer and Dudgeon, 2010).

The carideans shrimps are one of the most common and important invertebrates in terms of abundance and biomass inhabiting rivers and approximately 800 species live in freshwater environments, representing about a fifth of global shrimp diversity (Magalhães *et al.*, 2016). The families Atyidae and Palaemonidae comprise about 98 % of all freshwater shrimp species worldwide (De Grave *et al.*, 2015). Family Atyidae De Haan, 1849 comprises 44 genera, which include some 460 species of freshwater and estuarine shrimp (De Grave and Fransen, 2011; Christodoulou *et al.*, 2016; Jugovic *et al.*, 2019). Only four species belonging to two genera are reported for Brazil (Melo, 2003; Torati and Mantelatto, 2012): genus *Atya* Leach, 1816, which includes *Atya gabonensis* Giebel, 1875 and *Atya scabra* (Leach, 1816) (Fig. 1), and *Potimirim* Holthuis, 1954, which includes *Potimirim brasiliana* Villalobos, 1959 and *Potimirim potimirim* (Müller, 1881).

Atyids are characterized by a peculiarity of the external morphology of the first two pairs of pereiopods, which have brush-shaped ends with many setal tufts (Hobbs and Hart, 1982; Bauer, 2004). These shrimps are specialized for filter feeding, using their brushes to obtain organic matter from suspended particles or to sweep microbial biofilms (Chace, 1972; Souza and Moulton, 2005). Because of their special morphology, shrimps of the genus *Atya* are widely exploited in the ornamental freshwater aquarium trade (De Grave *et al.*, 2008; Mrugala *et al.*, 2019). Shrimp of the species *A. scabra* are generally found in rocky river beds, clean streams, and in places with fast water currents and high dissolved oxygen levels (Rocha and Bueno, 2004; Melo and Coelho, 2008). *Atya scabra* are also one of the resources exploited by artisanal fishermen (Buckup and Bond-Buckup, 1999; Almeida *et al.*, 2010).

Atya scabra has a wide amphi-Atlantic distribution, on the west coast of Africa, from Liberia to northern Angola (Hobbs and Hart, 1982; De Grave *et al.*, 2013), on the other side of the Atlantic ocean, on the east coast of the American continent, from Mexico to Brazil (Ceará, Rio Grande do Norte, Pernambuco, Sergipe, Bahia, Rio de Janeiro, São Paulo, Santa Catarina and Rio Grande do Sul), as well as across island countries in Central America, such as Dominica, Jamaica, Cuba, and Curaçao (Hobbs and Hart, 1982; Melo, 2003; Boos *et al.*, 2012; Pileggi *et al.*, 2013; Oliveira *et al.*, 2019).

Considering its remarkably large geographic distribution, *A. scabra* is considered as "Least Concern" by the International Union for Conservation of Nature (IUCN) (De Grave *et al.*, 2013). However, in 2008, *A. scabra* was listed as "Vulnerable" in the red book of Brazilian fauna threatened with extinction, *i.e.*, the species had a moderate risk of extinction in the wild, since its populations were decreasing in size throughout its geographic extent (Machado *et al.*, 2008). Melo and Coelho (2008) affirm that since 2002, populations of this species have been declining in some watersheds, and they have totally disappeared from others. More recently, in 2016, this species was assessed as "Near Threatened" in the red book of Brazilian crustaceans (Mantelatto *et al.*, 2016).

In this scenario, continuous anthropogenic impacts to the São Francisco River (*e.g.*, transporting its waters to other hydrographic basins, using the water to produce energy, urban and industrial supply, navigation, and fisheries for 20 million people) have environmental consequences, such as potential negative impacts on the fauna that inhabit this river (Sato and Godinho, 2004; Silveira *et al.*, 2016; Brito and Magalhães, 2017). Therefore, the main purpose of this investigation was to describe the population biology of the freshwater shrimp *A. scabra* in the lower São Francisco River, northeastern Brazil.

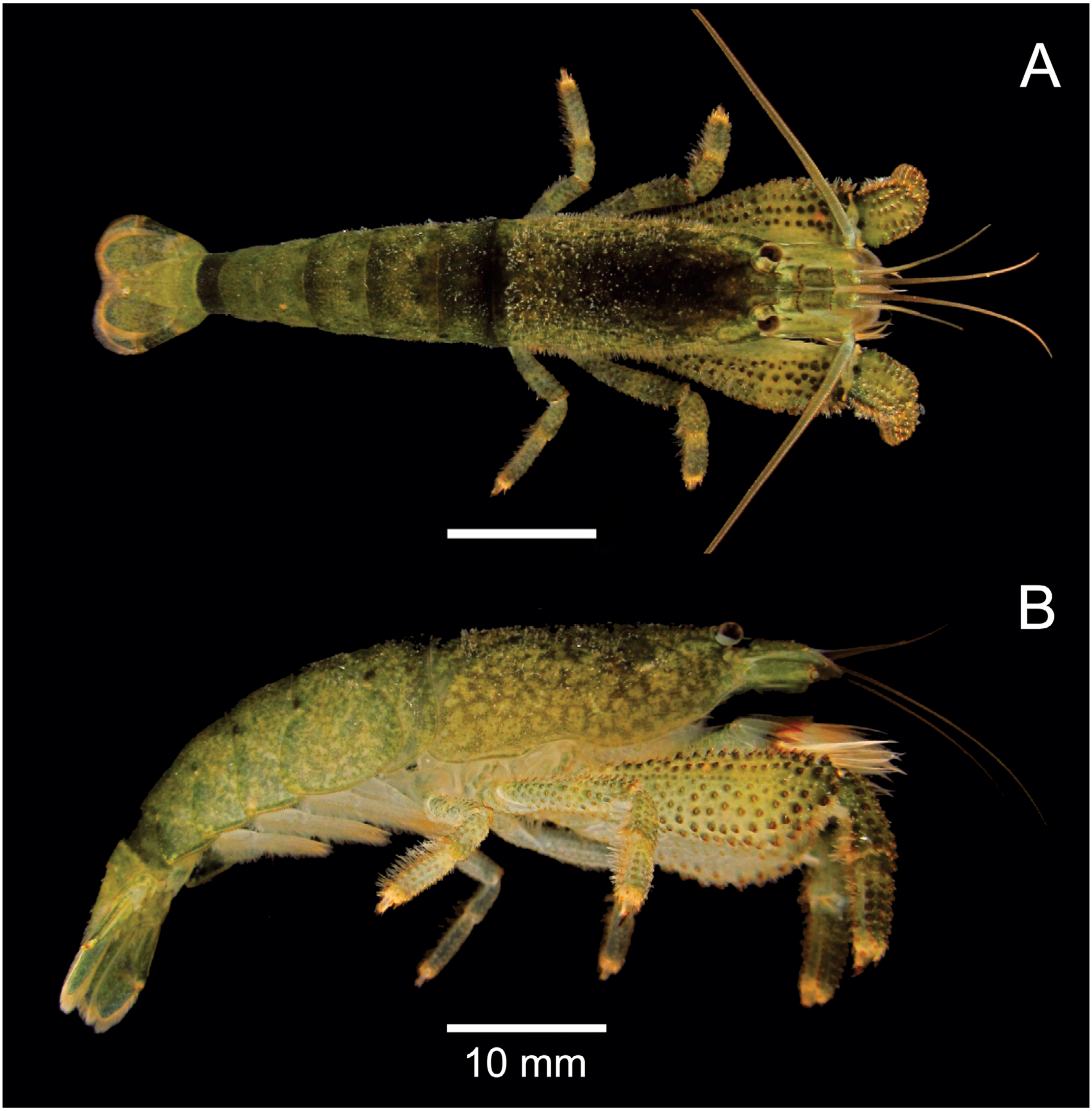

Figure 1. (**A**) Dorsal and (**B**) lateral view of *Atya scabra* (Leach, 1816) captured on the São Francisco River, Sergipe, Brazil (Photo: Alves, DFR).

Material and Methods

Study sites and sampling methods

Specimens of *A. scabra* were collected monthly from February 2015 to January 2016 in the lower São Francisco River, about 200 km from the mouth, in northeastern Brazil, Xingó Reservoir (09°39'27"S 37°40'44"W) (Fig. 2). The São Francisco River is one of the largest rivers in eastern South America (about 2900 km in length) and crosses five Brazilian states (Bahia, Minas Gerais, Alagoas, and Sergipe Pernambuco) (Welcomme, 1985). The headwaters are located in the state of Minas Gerais and the river ends in the Atlantic Ocean between Sergipe and Alagoas states (Santos *et al.*, 2012) (Fig. 2).

Figure 2. Map of Brazil indicating the São Francisco River watershed. Inset: sampling site (black circle) and the region of the Xingó Reservoirs (white circle). Legend: MG–Minas Gerais; BA–Bahia; SE–Sergipe; AL–Alagoas; PE–Pernambuco.

Four sampling sites (S) were selected, two on each riverbank, with a distance of about 500 m between them (S1, S2, S3, and S4). These sites were selected because they had stony stream beds with transparent waters, strong currents, and an absence of accumulated fine sediments, *i.e.*, ideal for the establishment of this filtering species (Almeida *et al.*, 2008; 2010). Each sampling site was considered a replicate, and they exhibited characteristics similar to each other.

Shrimps were collected at a mean depth of one meter, since this species frequents shallow waters (there are no records of *A. scabra* living in depths greater than 1 meter), where there is swiftly flowing water over a rocky substrate (Hobbs and Hart, 1982). The specimens were collected manually during snorkeling sessions. This sampling method was selected after a previous study, which showed low capture success using traps and hand nets, as performed by other authors (*e.g.*, Galvão and Bueno, 2000; Almeida *et al.*, 2010; Herrera-Correa *et al.*, 2013), but demonstrated the effectiveness of manual collection during snorkeling. During each month, a 20-m-wide transect was outlined parallel to the riverside in each sampling site. Two divers collected samples of *A. scabra* along this transect, with a standard catch effort of 30 min, totaling 1 h per site per month. After capture, specimens were placed in plastic bags and brought to the surface.

The sampling was carried out using a mark-and-recapture method, which consisted of the capture, marking and the attempted recapture of marked individuals in subsequent samplings (one month later). The individuals were marked with visible implant elastomer (VIE). VIE is a colored polymer supplied in liquid form that cures to a flexible solid with the addition of a curing agent (Northwest Marine Technology (NMT), Shaw Island, WA, USA). Once the polymer and curing agent are mixed, it can then be injected subcutaneously using a small-bore needle in a variety of body locations where there are clear or lightly pigmented tissues, so that it forms a permanent, visible, non-toxic mark (Woods and James, 2003). This type of tag has been previously used in decapod crustaceans and has shown good efficiency (*e.g.*, Davis *et al.*, 2004; Clark and Kershner, 2006). The specimens were marked according to the sampling site: S1, in the left side of abdomen; S2, in the right side of abdomen; S3, in the left side of telson; and S4, in the right side of telson. In addition, different colors were used to mark the sampling months. After the specimens were measured, sexed and marked, the individuals were returned to the river, in the same site from where they were captured.

In each sampling site, temperature (°C), rainfall (mm), and water flow (m^3/s) were recorded monthly. Temperature was measured with a thermometer. Rainfall data during the sample period were provided by the Instituto Nacional de Pesquisas Espaciais (INPE) through their official website (http://sinda.crn2.inpe.br/PCD/SITE/novo/site/index.php). Flow data during the sample period were provided from the Agência Nacional de Águas (ANA) of the Ministério do Meio Ambiente. Water flow of the studied region is controlled by the Xingó Reservoir, and varied between 261 and 2323 m^3/s during the period of study.

Population biology of the Atya scabra

In the field, the individuals were identified according to Melo (2003). This species is characterized by the presence of chelipeds on the first two pairs of pereiopods with tufts of dense setae on the propodus and dactylus (Fryer, 1977). This species also has a robust third pereiopod, with the propodus elongated and flat, and a somewhat sculptured carapace (Melo, 2003).

Specimens were measured for carapace length (CL), *i.e.*, the distance between the postero-orbital margin and the posterior margin of the carapace, with Vernier calipers to the nearest 0.01 mm. The specimens were separated into the following demographic categories: males, non-ovigerous females, ovigerous females, and juveniles. Specimens were sexed based on the presence or absence of the male appendix masculina, located on the second pair of pleopods (Galvão and Bueno, 2000). Adult male individuals were classified by the presence of a completely developed appendix masculina on the second pleopods, as in Almeida *et al.* (2010). Adult female individuals were classified according to the size of the smallest ovigerous females obtained throughout the sampling period (Bauer, 1989). Juvenile individuals were classified by absence of the appendix masculina and smaller than smallest ovigerous individuals (Mattos and Oshiro, 2009). To evaluate the population biology of *A. scabra*, size-frequency distributions were constructed using 2.0 mm CL intervals for both males and females. The individuals were distributed into 11 size classes, from 6.3 to 28.3 mm CL.

Moreover, other population parameters were calculated, such as the proportion of ovigerous females and the sex ratio. The proportion of ovigerous females was estimated monthly as the number of females carrying eggs on the abdomen relative to the total number of adult females. Sex ratio was estimated monthly as the quotient between the number of males and the number of males plus females in the population. Thus, sex ratio values higher or lower than 0.5 indicated populations skewed toward males or females, respectively. For each month, we tested deviations from a 1:1 sex ratio using a binomial test (Wilson and Hardy, 2002). In these monthly analyses (proportion of ovigerous females and sex ratio) all individual samples were considered, including those that were recaptured.

Analysis of results

The model's assumptions of homoscedasticity (Levene's test) and normality (Shapiro–Wilk's test) of the population size distribution were tested first (Zar, 2010). The mean size (CL) was compared between males and females by the non-parametric Mann-Whitney test ($a < 0.05$) (Zar, 2010). For this analysis, recaptured individuals were not considered to avoid overestimating the body size-distribution of the population, since an individual could appear in more than one sampling. To verify possible migrations between the sites, the percentage of recaptures was calculated by sampling site. Thus, to verify if *A. scabra* were territorial, the percentage of recaptured males and females was calculated. For this analysis, the chi-square test (χ^2) was applied to verify differences in recapture rates between the sexes ($a < 0.05$) (Zar, 2010).

To test for variations in *A. scabra* abundance throughout the sampled period, a linear regression analysis was performed. For this analysis, the sampling month was considered the predictor variable, while the number of individuals of shrimps was used as the response variable, considering the abundance of shrimp at each site as a sample. To verify any association of the environmental factors (temperature, rainfall, and water flow) with *A. scabra* abundance, a multiple linear regression was used. In addition, a multiple linear regression was also used to verify any association of environmental factors (temperature, rainfall, and water flow) with the abundance of ovigerous females.

Results

A total of 233 specimens of *A. scabra* were collected, including 120 males (51.5 %), 71 non-ovigerous females (30.5 %) and 42 ovigerous females (18.0 %). Of the 71 non-ovigerous females, only three juveniles were observed. The total sex ratio did not differ significantly from a 1:1 (Sex ratio = 0.51, binomial test; $P = 0.694$; recaptured individuals excluded).

The size-frequency distribution indicated a unimodal and non-normal distribution for the *A. scabra* population (Shapiro-Wilk; $W = 0.974$; $P < 0.001$, Fig. 3). A total of 55 individuals were recaptured, resulting in a general recapture rate of 19.09 %. Of the recaptured individuals, 80 % (N = 44) were males and 20 % (N = 11) were females. Significant differences were observed between the frequencies of recaptured males and females (Chi-square = 19.8; *d.f.* = 54; $P < 0.001$). Individuals were recaptured in all sampling sites, 8.93 % (N = 5), 22.2 % (N = 12), 12.90 % (N = 4) and 23.13 % (N = 34), in S1, S2, S3, and S4, respectively. Recaptured individuals were always observed in the same site in which the individuals were first recorded, *i.e.*, migrations between sites were not observed during the study period.

The mean (± SD) size of males was 17.71 ± 3.85 mm CL, in which the smallest and largest male measured 8.80 and 26.70 mm CL, respectively. The mean (± SD) size of females (non-ovigerous and ovigerous) was 13.14 ± 2.59 mm CL, in which the smallest and largest female measured 6.30 and 23.40 mm CL, respectively. The smallest ovigerous female measured 9.50 mm CL. Significant differences were observed between the sizes of *A. scabra* males and females (Mann-Whitney; $U = 2149.0$; *d.f.* = 232; $P < 0.000$). *Atya scabra* were distributed in 11 size classes with intervals of 2.00 mm CL. Males were observed in all size classes, with the exception of the first class (6.30⊢8.30 mm CL), while females were not observed in the 20.30⊢22.30 mm size class CL and in the largest size classes (24.30⊢26.30 and 26.30⊢28.30 mm CL). Ovigerous females were observed in the 8.3⊢10.3 mm CL to 18.3⊢20.3 mm CL size classes (Fig. 3).

Ovigerous females were observed in all sampling months, with the exception of January 2016, for which only males were recorded. The highest absolute number of ovigerous females was observed in February 2015 (N = 16), followed by May 2015 (N = 7). The highest proportion of ovigerous females was recorded in November (0.75), however, in this month only four females were sampled (Fig. 4A). The sex ratio did not differ significantly from a 1:1 ratio during most months (binomial test; $P > 0.05$). During March 2015 the sex ratio deviated from 1:1, and it was slightly skewed toward males (binomial test; $P < 0.05$, Fig. 4B) and in January 2016 only males were recorded.

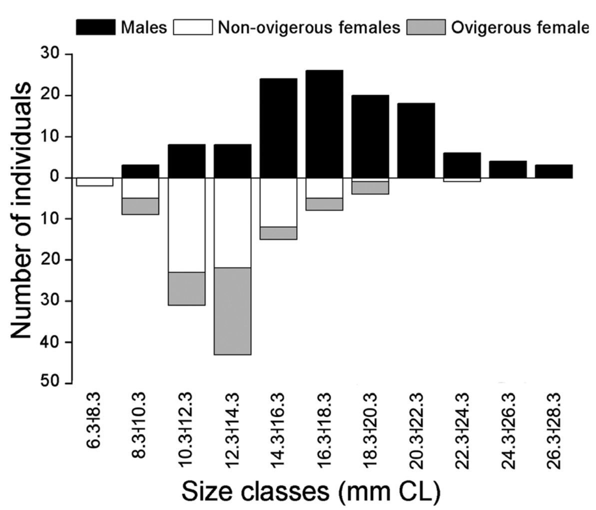

Figure 3. *Atya scabra* (Leach, 1816). Size-frequency distribution of carapace length (mm) of the male and female shrimp sampled in São Francisco River, Sergipe, Brazil.

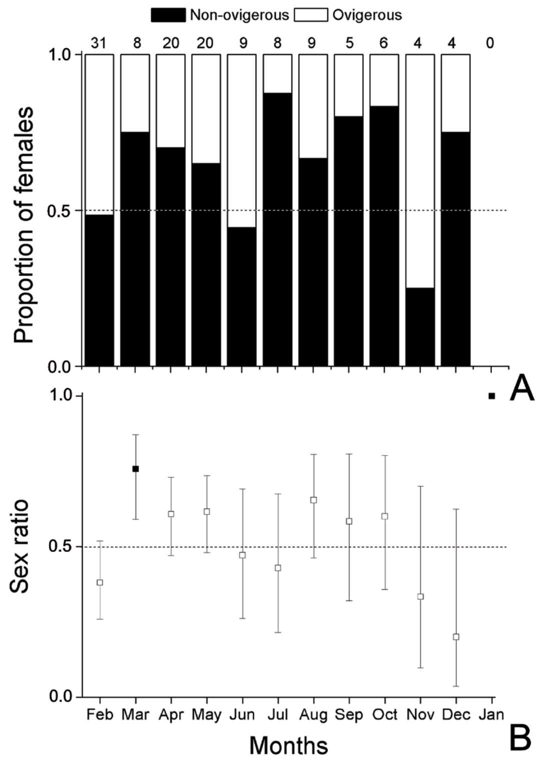

Figure 4. *Atya scabra* (Leach, 1816). (**A**) Proportion of adult ovigerous and non-ovigerous females and (**B**) sex ratio (estimate ± SE) during the months sampled. In (**B**), the black square indicates a deviation from a 1:1 sex ratio.

A decrease in abundance of *A. scabra* was observed throughout the sampling period (Linear regression; $R^2 = 0.32$; $F = 22.18$; $P < 0.001$), indicating a decline of about 90 % for this population in the region studied (Fig. 5A). A positive correlation between *A. scabra* abundance and water flow was observed (Multiple regression; $F = 13.43$; $P < 0.001$, Fig. 5B). On the other hand, the abundance of *A. scabra* did not vary with other environmental factors (temperature and rainfall) (Multiple regression; $P > 0.05$). A positive correlation between abundance of ovigerous females *A. scabra* and rainfall also was observed (Multiple regression; $F = 13.14$; $P < 0.01$, Fig. 5C). Similarly, the abundance of ovigerous females of *A. scabra* did not vary with other environmental factors (temperature and flow water) (Multiple regression; $P > 0.05$, Fig. 5C).

Discussion

Population biology

Sampling was performed in the present study following the first formal record of *Atya scabra* for

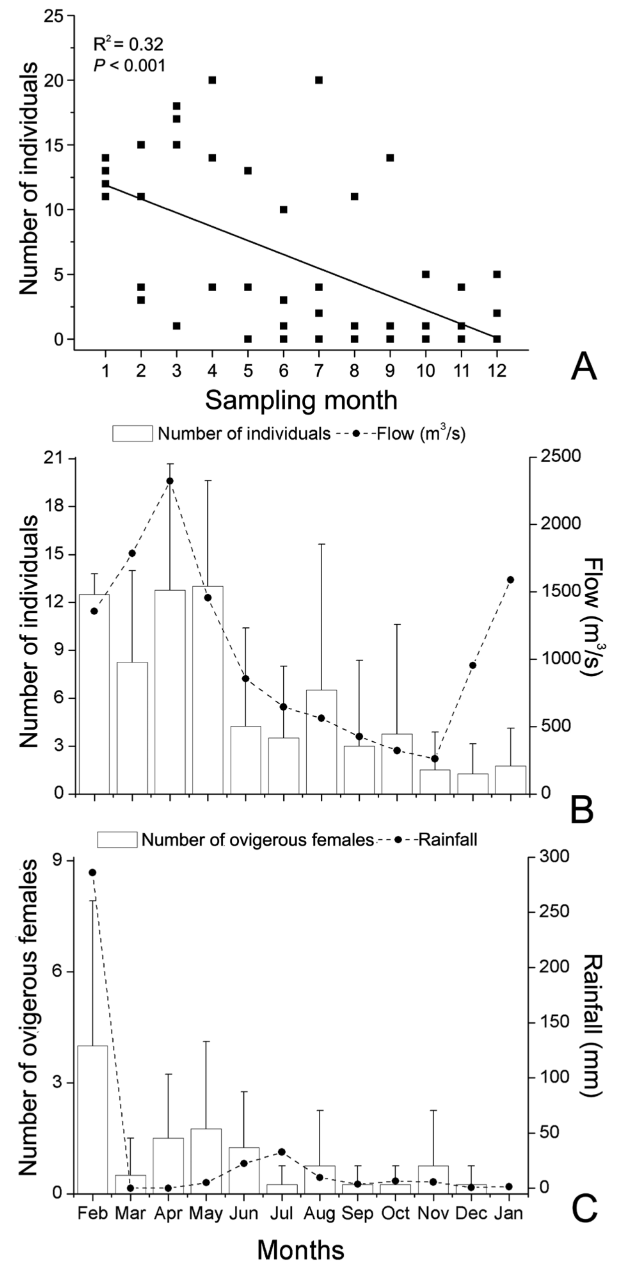

Figure 5. *Atya scabra* (Leach, 1816). (**A**) Relationship between sampling month and number of individuals; (**B**) monthly variation in the number of individuals (average ± SD) and mean flow (m³/s) and (**C**) monthly variation in number of ovigerous females (average ± SD) and mean rainfall (mm) during the sampling period.

Sergipe State, Brazil by Oliveira *et al.* (2019). Despite Almeida *et al.* (2008) stating that this species occurs in Sergipe, no biological studies have been published with *A. scabra* individuals sampled in this locality. Their statement was based on extrapolation of its occurrence, since *A. scabra* had been found in adjacent regions, in the states of Ceará, Pernambuco Alagoas, and Bahia (Hobbs and Hart, 1982; Melo, 2003; Almeida *et al.*, 2008; Pileggi *et al.*, 2013). This knowledge gap in the geographic distribution of this species is due mainly to the late records for this species in the state of Sergipe. The lack of previous sampling in this region, or its cryptic habitats, make this species difficult to sample, as it has generally been found in riverbeds and places with fast flowing currents (Rocha and Bueno, 2004; Melo and Coelho, 2008).

The number of individuals sampled in this study (N = 233) is low when compared to a study by Almeida *et al.* (2010) (N = 3752) in Bahia, but higher than that reported by Herrera-Correal *et al.* (2013) (N = 74) in São Paulo, both of which were carried out in Brazil. The difference in the number of individuals sampled may be related mainly to the methodology (sampling period and methods) and the geological characteristics of the river being sampling. The great difference in abundance observed in the study of Almeida *et al.* (2010) could be related to the sampling site, which was about 10 km from the mouth of the Santana River (Bahia), when compared to the present study, where the shrimp were sampled about 200 km from the mouth of the São Francisco River. In this sense, it is important to emphasize that *A. scabra* are considered to be amphidromous (McDowall, 2007; Bauer, 2013), *i.e.*, the individual grows, mates and spawns in freshwater streams or rivers, but the planktonic larvae develop in brackish water estuaries or marine coastal waters. Upon the completion of larval development, the individual settles to the bottom as a postlarva and finds the mouth of a freshwater stream or river to migrate upstream where adults of the species are found (Hunte, 1979; Abrunhosa and Moura, 1988; Bauer, 2013). As observed in the study of Almeida *et al.* (2010), a larger number of this species should be expected when sampling closer to the mouth, despite the migrations observed for this species.

The presence of ovigerous females was also observed throughout the study period, with a reproductive peak associated with rainfall, which indicates continuous seasonal reproduction. The same pattern of continuous reproduction was observed for *A. scabra* by Galvão and Bueno (2000) and Almeida *et al.* (2010) and for *Atya margaritacea* A. Milne-Edwards, 1864 by Martínez-Mayén and Román-Contreras (2000). In these studies, reproductive peaks were also observed during the rainy season, probably to facilitate the downstream larval dispersal of these amphidromous shrimp. This mechanism has also been observed in other species of caridean shrimps [(*e.g.*, *Macrobrachium acanthurus* (Wiegmann, 1836), *Macrobrachium carcinus* (Linnaeus, 1758) (Valenti *et al.*, 1986), and *Macrobrachium olfersi* (Wiegmann, 1836) (Mossolin and Bueno, 2002)]. In contrast, the study of Palacios *et al.* (2008) performed on *A. margaritacea*, showed ovigerous females only appeared in the rainy seasons. According to the results obtained in this study and the studies mentioned above for other species of *Atya*, females obviously regulate the reproductive period according to the rainy season. This reproductive strategy is probably related to the use of the greatest river flow during this period, which can facilitate the loading of the larvae downstream to develop in the estuary. However, at the site of the present study, the water flow was controlled by the Xingó Reservoir, which in rainy periods tends to decrease this flow. Therefore, such flow controls could cause harm to the population of *A. scabra* that live in this region, since females reproduce naturally during a period of higher rainfall. With this anthropogenic control, larvae hatch in periods with low flow in the river and may not reach the estuaries, implying problems in development and recruitment of the population.

In this study, males were larger than females. This pattern of sexual dimorphism (males attaining larger body sizes than females) suggests strong male-male competition for receptive females as suggested by sexual selection theory (Shuster and Wade, 2003). These results corroborate with other studies carried out with other species in the genus [*e.g.*, *A. margaritacea* (Martínez-Mayén and Román-Contreras, 2000; Palacios *et al.*, 2008), and *A. lanipes* Holthuis, 1963 (Covich *et al.*, 2003)] and as reported by Galvão and Bueno (2000) for the same species in São Paulo State (Brazil) and by Darnell (1956) in Mexico. Our results support the idea that adult males may exhibit a degree of territoriality, since they were recaptured more often than females and always were recaptured at the same site of their first record. On the other hand, adult females were less recaptured, indicating that they may migrate downstream to facilitate larval drift during the hatching period.

In general, in the present study, the sex ratio of *A. scabra* did not differ significantly from 1:1. In species with separate sexes, as in *A. scabra*, sex allocation theory predicts that an equal number of males and females must be produced (the primary sex ratio) since frequency-dependent selection will act against the more common sex in the population (Fisher, 1930; Charnov, 1982; West, 2009). The current 1:1 sex ratio matches that found in the population of the same species studied by Almeida *et al.* (2010). However, the sex ratio of *A. scabra* was skewed significantly in March 2015 and was biased towards males. In February 2015 and May 2015 a greater number of ovigerous females were also observed, corroborating the suggestion that ovigerous females migrate during this period while males remain territorial.

In this study, some evidence points to the fact that the population of *A. scabra* in the São Francisco River consists primarily of adults and probably includes a reduced number of juveniles. This evidence includes: 1) only three juvenile individuals were observed during the sampling period; 2) the smallest female (6.3 mm CL) recorded in this study was larger than the smallest ovigerous female (5.4 mm CL) recorded by Almeida *et al.* (2010); 3) juvenile males were not recorded and all sampled males had the appendix masculina completely developed. The absence of juveniles was also observed in the studies by Darnell (1956), Galvão and Bueno (2000) and Martínez-Mayén and Román-Contreras (2000). These authors justify this absence by means of behavioral characteristics, such as size segregation related to several river microenvironments or by these juveniles associating with submerged roots of plants along the bank; as suggested by Almeida *et al.* (2008). Moreover, the almost complete absence of juveniles recorded in this study could be related to the process of upstream migration, since *A. scabra* is an amphidromous species (Bauer, 2013). However, according to Kikkert *et al.* (2009), the upstream migration is carried out by post-larvae in the genus *Atya*. Despite this statement, our results indicate that in some cases the migration extends into the juvenile phase, and that only during the adult phase does this species become territorial, because adult individuals were not recaptured in other sites away from where they were first recorded. This hypothesis can be reinforced by the great distance of the estuarine region in which early development (pre-juvenile) occurs relative to the localities in which the studied population was recorded (about 200 km).

Evidence of a population at risk of extinction

In this study, we evaluate the population structure of *A. scabra* in the stretch of the lower São Francisco River, northeast of Brazil, during one year. In 2016, this species was assessed as "Near Threatened" in the red book of Brazilian crustaceans (Mantelatto *et al.*, 2016). A population decline of *A. scabra* was previously highlighted in some regions, in the states of Rio de Janeiro and Espírito Santo, with indications of local extinctions, and in some watersheds the species disappeared completely (Melo and Coelho, 2008). In the present study, a decline of approximately 90 % of the population was observed after one year of sampling in the São Francisco River, from which it was possible to only detect seven specimens of *A. scabra* in January 2016. At the end of this study, other collections were attempted in the same sampling sites (*e.g.*, March 2016 and September 2017) and no specimens of *A. scabra* were observed (personal observation), suggesting that such a decline is not an annual variation in abundance.

During the study period, some environmental changes were verified at the sites sampled in the São Francisco River. They were directly related to the reduction of water flow in the São Francisco River, and probably contributed to the population decline of *A. scabra*; among them: 1) a reduction in water flow of the São Francisco River to 1,000 m^3/s from the Sobradinho and Xingó reservoirs in April 2015; and 2) a second reduction in water flow to 900 m^3/s from the same reservoirs in June 2015. Even now, there is evidence that the dams are now required to release only 550 m^3/s, compared with the historical average of 2900 m^3/s in this section of the river (Villela, 2017). Dry periods can change the distribution of species in many regions, where the water discharge is usually seasonal (Chapman and Kramer, 1991; Rincon and Cressa, 2000). These habitats become critical to several species, especially those that migrate upstream from coastal estuaries (Benstead *et al.*, 2000; Covich *et al.*, 2003), as is true for *A. scabra*. Some immediate effects of high flows on decapod communities have been documented (Covich *et al.*, 1991; 1996; Johnson *et al.*, 1998) as well as the short-term effects of low flows on pool habitats, and on the abundance of freshwater shrimp (Covich *et al.*, 1998; 2000).

In addition, *A. scabra* shrimp are generally found in places with fast currents and are specialized for filter feeding in these environments (Chace, 1972; Rocha and Bueno, 2004; Souza and Moulton, 2005; Melo and Coelho, 2008). In this sense, the reduction of the water flow of the São Francisco River can negatively influence food capture, since this shrimp uses the current to filter feed, and because of this, has little energy costs. In addition, the absence of juveniles is strong evidence that recruitment failed during the study period. This interruption of the upstream return migration of the post-larvae, is indicative of the negative human impacts on this migration, contributing to the decrease of this population in the studied region.

Only a small portion of *A. scabra* populations are actually protected by Conservation Units. Direct actions for the conservation of atyids shrimps in Brazil are provided in the "Plano de Ação Nacional para a Conservação das Espécies Aquáticas Ameaçadas de Extinção da Bacia do Rio Paraíba do Sul" (São Paulo, Rio de Janeiro and Minas Gerais), established by Resolution ICMBio Nº 131, of December 14, 2010 and improved by Resolution ICMBio Nº 17, of October 11, 2012 and in the "Plano de Ação Nacional para Conservação das Espécies Ameaçadas e de Importância Socioeconômica do Ecossistema Manguezal", established by Resolution ICMBio Nº 9, of January 29, 2015, which also provides actions for protection of *Atya scabra* (Mantelatto *et al.*, 2016).

Evaluation of the conservation status of *A. scabra* identified that the main threats to their populations were those related to the destruction of their habitats, such as the construction of dams, water extraction, river and estuarine pollution, degradation of water quality, reduction of water flow, and overfishing (De Grave *et al.*, 2015; Mantelatto *et al.*, 2016); all of which could potentially interrupt the longitudinal migration of the amphidromous life cycle of this shrimp (Bauer, 2011). Brazil has a history of human activities that degrade its rivers (Escobar, 2015) and the water flow in rivers continues to decrease, as it has for three decades (Villela, 2017). The presence of dams causes slow-flowing waters, often with high levels of salinization, and many native species become locally extinct while non-native species flourish because they are adapted to these new conditions (Assis *et al.*, 2017). Such mistakes cannot continue if we are to protect both human populations and native biota. Therefore, studies aimed at understanding the ecology and biology of these threatened freshwater species becomes essential to increase knowledge about these populations. Moreover, the Brazilian federal government must take urgent action to implement ecological restoration efforts to ensure that future generations can continue to use the ecosystem services provided by rivers. Significant legislative actions, including protection at the local level, need to be taken to protect this fragile ecosystem.

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