Nauplius
The Journal of The Brazilian Crustacean Society

e-ISSN 2358-2936
www.scielo.br/nau
www.crustacea.org.br

Morphometric aspects of two coexisting amphidromous shrimps, *Atya gabonensis* Giebel, 1875 and *Atya scabra* (Leach, 1816), in the Paraíba do Sul River, Brazil

Abner Carvalho-Batista[1,2] orcid.org/0000-0001-8193-1269
Caio M.C.A. Oliveira[1] orcid.org/0000-0002-4662-1422
Guilherme Souza[3] orcid.org/0000-0002-0834-6415
Fabrício Lopes Carvalho[4] orcid.org/0000-0001-7851-0578
Fernando Luis Mantelatto[1] orcid.org/0000-0002-8497-187X

1 Universidade de São Paulo (USP), Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto (FFCLRP), Departamento de Biologia, Laboratório de Bioecologia e Sistemática de Crustáceos (LBSC). Av. Bandeirantes, 3900, 14040-901, Ribeirão Preto, São Paulo, Brazil.
AC-B E-mail: carvbatis@gmail.com
FLM E-mail: flmantel@usp.br

2 Universidade Paulista (UNIP), Instituto de Ciências da Saúde, Avenida Marquês de São Vicente, 3001, 05037-040, São Paulo, São Paulo, Brazil.

3 ONG Projeto Piabanha. Campo de Sementes, 28570-000, Caixa Postal 123546, Zona Rural / Itaocara, Rio de Janeiro, Brazil.
GS E-mail: guilhermesouza.bio@gmail.com

4 Universidade Federal do Sul da Bahia (UFSB), Centro de Formação em Ciências Agroflorestais (CFCAf), Grupo de Pesquisa em Carcinologia e Biodiversidade Aquática (GPCBio). Rodovia Ilhéus-Itabuna, km 22, CEPEC/CEPLAC, 45662-200, Ilhéus, Bahia, Brazil.
FLC E-mail: flcarvalho@ufsb.edu.br

ZOOBANK: http://zoobank.org/urn:lsid:zoobank.org:pub:6B13D127-5657-47C7-9087-C6FDCFD31969

Corresponding Author
Abner Carvalho-Batista
carvbatis@gmail.com

SUBMITTED 21 March 2020
ACCEPTED 03 December 2020
PUBLISHED 16 April 2021

DOI 10.1590/2358-2936e2021018

Abstract

Atya gabonensis Giebel, 1875 and *Atya scabra* (Leach, 1816) are amphidromous shrimps. In some areas, these species populations are vulnerable due to the anthropogenic impact on their habitats and commercial exploitation. However, basic morphometric data is still lacking. This study provides morphometric data on both species in the Fluvial Island Domain of Paraíba do Sul River basin, Brazil. Sampling was performed bimonthly from January 2013 to March 2014. Individuals were analysed according to sex, weight, carapace length and width, abdomen length, second abdominal pleura height and width, length of third pereopod articles, and length and width of the male appendix interna. We sampled 42 individuals of *A. gabonensis* and 16 individuals of *A. scabra*. In both species, females showed abdomen and second abdominal pleura larger than males, while males showed third pereopod articles larger than females, both related to sexual dimorphism. We detected differences in the carapace length × carapace width relationship and in the growth pattern of the male appendix interna between species, with *A. gabonensis* presenting the carapace and the male appendix interna wider than *A. scabra*. Morphometric aspects of both species are unpublished for this region, and this data is valuable for *A. gabonensis* in the western Atlantic and for *A. scabra* from Rio de Janeiro state. Such information is essential for future systematic assessment and establishment of conservation management policies.

Keywords

Atyidae, biogeography, Caridea, Fluvial Island Domain, systematics.

Introduction

Atya gabonensis Giebel, 1875 and *Atya scabra* (Leach, 1816) are phylogenetically close species of the family Atyidae De Haan, 1849 (Page *et al.*, 2008; von Rintelen *et al.*, 2012; Oliveira *et al.*, 2019) with an amphidromous life cycle: their larvae are dependent on estuarine or marine environments (McDowall, 2007; Bauer, 2013). The adults feed mainly on planktonic algae, organic debris and insect parts (Chace, 1972; Fryer, 1977; Obande and Kusemiju, 2008) and are distributed in the countries of South, Central and Caribbean America as well as in western Africa (Hobbs and Hart, 1982; Melo, 2003). *Atya gabonensis* and *A. scabra* are target species of artisanal fishing at different intensities, both in Brazil and Africa (Oliveira, 1945; Motoh and Murai, 2006; Kadjo *et al.*, 2016), and present significant interest in the aquarium trade (Werner, 2003; Lipták and Vitázková, 2015; Weiperth *et al.*, 2019).

Despite the wide geographic distribution and commercial interest, there are still few studies on the population biology of these two species. For *A. gabonensis*, the scarcity of information is evident, and studies are restricted to the populations of the African continent. In Brazil, so far, there are mainly studies focusing on the diagnosis of the species and reporting its occurrence (Hobbs, 1980; Fonseca *et al.*, 1994; Ramos-Porto and Coelho, 1998; Melo, 2003). Galvão and Bueno (2000) studied the population structure of *A. scabra* and its reproductive biology in the Guaecá River, in the city of São Sebastião, while Herrera-Correal *et al.* (2013) studied the fecundity and reproductive output at São Sebastião Island, both located on the northern coast of São Paulo state. Almeida *et al.* (2010) and Barros *et al.* (2020), as well, investigated several aspects of the reproductive biology of this species in southern Bahia. However, there is a clear lack of information about populations of *A. scabra* in other locations throughout Brazil, and information on *A. gabonensis* in American regions remains scarce. This has led to *A. scabra* and *A. gabonensis* being considered as Near Threatened - NT and Data Deficient - DD, respectively, in the latest evaluation made for species inhabiting the Brazilian territory (Mantelatto *et al.*, 2016).

The presence of these species was recorded during the monitoring of the aquatic fauna of the Paraíba do Sul River islands (Carvalho *et al.*, 2019). This is the last stretch of the lower middle course of the Paraíba do Sul River, between the cities of São Sebastião do Paraíba and São Fidélis, covering the municipalities of Aperibé, Cambuci, Itaocara and Santo Antonio de Padua, Rio de Janeiro state (Souza *et al.*, 2007). It is also found in the Pomba and Grande rivers. Environmental diversification in the area is high, represented by a relatively conserved riparian forest mosaic with various depths and different hydrodynamic conditions caused by the presence of islands (Bizerril, 1998).

The capture of shrimps of the genus *Atya* has been reported among fishermen of the Fluvial Island Domain (Souza *et al.*, 2007), indicating that both species are under fishing pressure in this region, especially for human consumption by local people. In addition, the Paraíba do Sul River basin is located in one of the most industrialised regions of Brazil (between the states of Minas Gerais, São Paulo and

Rio de Janeiro) (Marengo and Alves, 2005; Devide *et al.*, 2014), with a history of intense deforestation of riparian forests (Dantas *et al.*, 2000), water pollution in most of the municipalities (Cavadas-Barcellos *et al.*, 2011), installation of dams and hydroelectric plants, numerous environmental accidents and the introduction of exotic species (Polaz *et al.*, 2011; Moraes *et al.*, 2017).

In this context, the present study aims to provide unprecedented information about these populations for *A. gabonensis* on the American continent and for *A. scabra* in the state of Rio de Janeiro, Brazil. Such information can provide a scientific basis for future reassessment of the genetic diversity, for the monitoring of these species, as well as for developing sustainable fishing strategies and management policies for this region.

Material and Methods

Sampling

Specimens of *A. gabonensis* and *A. scabra* were collected bimonthly from manual collections performed by a 30-minute active search via free diving by a local fisherman. Sampling was performed from January 2013 to November 2014 at six sites in the Fluvial Island Domain of the Paraíba do Sul River. Three sites were located in the course of the Paraíba do Sul River and three in the tributaries: Pomba River and Grande River (Fig. 1). This region can be considered a priority area for the conservation of aquatic endangered species (Polaz *et al.*, 2011) since there are large parts of the river in continuity with the estuary.

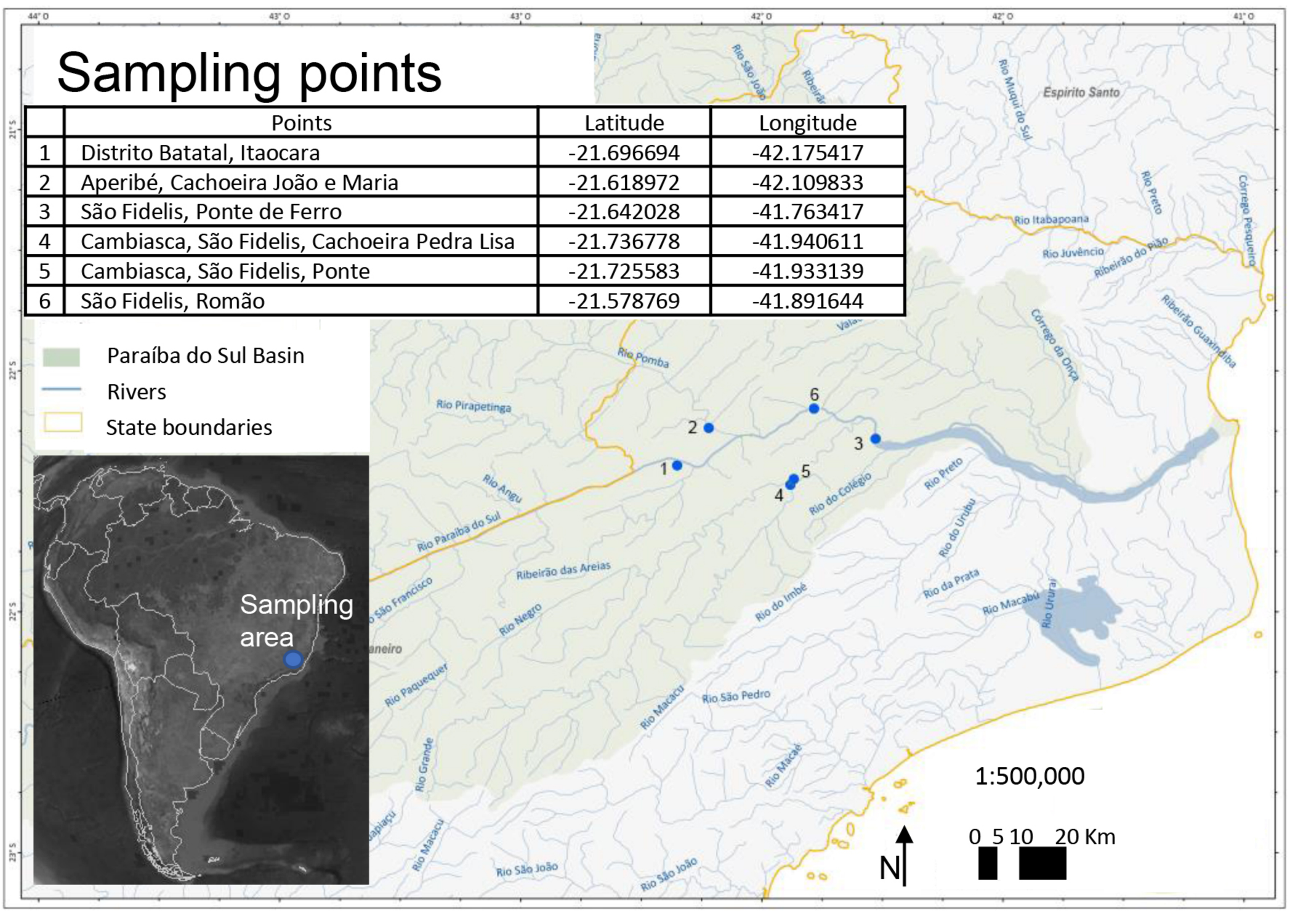

Figure 1. Sampling sites for shrimp of the genus *Atya* Leach, 1816 in the Fluvial Island Domain in the Paraíba do Sul River basin (modified from Carvalho-Batista *et al.*, 2019). NOTE: Crustacean sampling sites/Paraíba do Sul River Basin/Main Hydrography/State Limits.

After capture, individuals were placed in labelled plastic bags and frozen. At the laboratory, individuals were thawed and stored in 80 % ethanol in the Decapod Crustacean Collection of the Department of Biology (CCDB), at the Faculty of Philosophy, Sciences and Letters at Ribeirão Preto, University of São Paulo, Brazil. All individuals were identified to the species level, following Melo (2003), and sexed, based on the presence of the male appendix interna on the second pair of pleopods.

Carapace length (CL) was measured in millimetres and standardised as an independent variable. We used the Student's t-test to compare the carapace length of males and females. All individuals were weighed on a 0.1 g precision digital scale. The relationship between carapace length and individual weight was represented by the equation $y = ax^b$, where "y" is the individual's weight, "x" is the length of the carapace, "b" is the allometric coefficient of the structure studied and "a" is the line intercept on the ordinate axis. The other measurements were as follows: total length (TL), carapace width (CW), abdomen length (AL), width of abdomen at the second segment (AW), height and length of the second abdominal pleura (PH and PL, respectively), length of the merus (MerL), carpus (CarL), propodus (ProL), dactylus (DacL) of the third pereopod, length and width of the male appendix interna (AmL and AmW) and ratio L/W of Am (Fig. 2), which were used as dependent and CL-related variables.

The parameters were estimated by linear regression of logarithmic data, *i.e.*, with a linear version of the model ($\log y = \log a + b x \log x$). Comparisons between males and females in terms of the measured ratios were performed by covariance analysis (ANCOVA). The allometric state of each structure was analysed (b > 1 - positive allometry; b < 1 - negative allometry; b = 1 - isometry), and the null hypothesis H0 (b = 1) was tested by the Student's t-test for linear regression ($\alpha = 0.05$) (Zar, 1999). All analyses assumed a significance level of 0.05, and all data were tested for normality and homoscedasticity; when data did not meet these assumptions, the corresponding nonparametric tests were used.

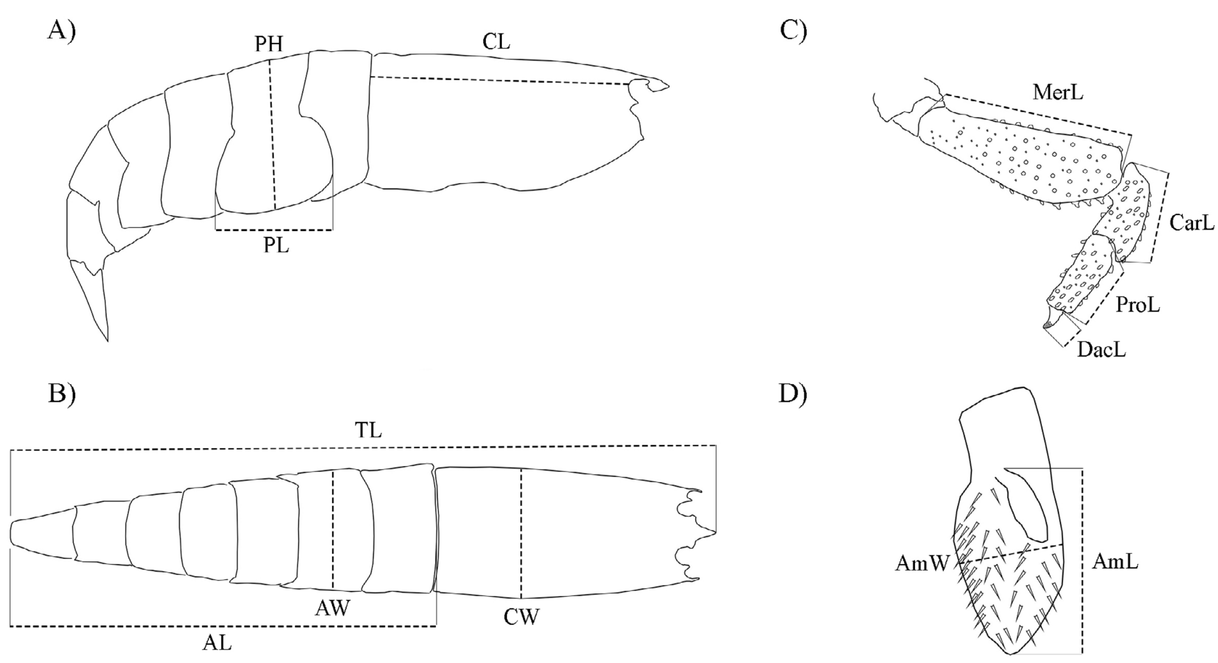

Figure 2. Dimensions used in the morphometric analyses of *Atya* Leach, 1816. **A**, (CL) carapace length, (PL) length of second abdominal pleuron, (PH) height of second abdominal pleuron; **B**, (CW) carapace width, (TL) total length, (AW) abdomen width, (AL) abdomen length; **C**, (MerL) merus length, (CarL) carpus length, (ProL) propodus length, (DacL) dactylus length; **D**, (AmL) length of male appendix interna, (AmW) width of male appendix interna.

Results

Atya gabonensis

In total, 42 individuals were sampled: 17 (40.5 %) males and 25 (59.5 %) females. The carapace length of males ranged from 19.54 to 58.49 mm, with an average of 41.26 ± 11.01 mm, while that of females ranged from 25.74 to 46.40 mm, with an average of 39.18 ± 5.28 mm. The overall average was 40.02 ± 7.92 mm.

The weight of males ranged from 3 to 85 g (mean = 35.6 ± 26.1 g), while that of females ranged from 8 to 44 g (mean = 26.7 ± 18.7 g); the overall average was 30.3 ± 18.7 g. The relationship between carapace length and individual weight was described by the potential equation $y = 0.0002CL^{3.1895}$, where y is the weight and CL is the carapace length in mm, with a determination coefficient (R^2) of 97 %. There was no statistically significant difference between sexes for the CL × weight relationship (p <0.05) (Fig. 3).

The total length of males ranged from 51.4 to 137.6 mm, with an average of 103.0 ± 24.1 mm; females ranged from 75.6 mm to 124.1 mm, with an average of 102.5 ± 12.0 mm. The overall average was 102.7 ± 17.7 mm. The CL × CW relationship was the only one that showed no statistically significant difference between sexes (Tab. 1). The equations that describe each of these relationships, as well as each R^2, are shown in Figure 4. Both sexes presented negative allometry for

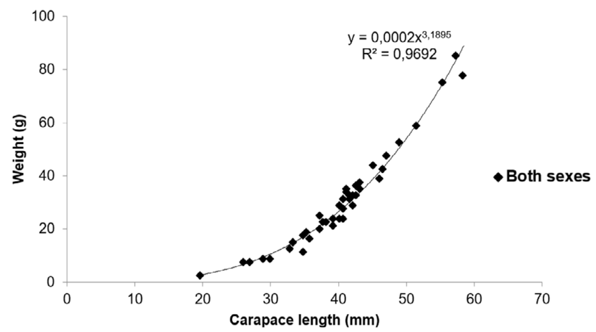

Figure 3. Relationship between carapace length and weight of *Atya gabonensis* Giebel, 1875 in the Fluvial Island Domain in the Paraíba do Sul River basin.

Table 1. Results of the Covariance Analysis (ANCOVA) of morphometric data for *Atya gabonensis* Giebel, 1875 at the Fluvial Island Domain in the Paraíba do Sul River basin. (CL) carapace length, (PL) length of the second abdominal pleuron, (PH) height of the second abdominal pleuron, (CW) carapace width, (TL) total length, (AW) abdomen width, (AL) abdomen length, (MerL) merus length, (CarL) carpus length, (ProL) propodus length, (DacL) dactylus length. Significant difference: * P <0.05; ** P <0.01.

Relationship	Factor (Group)	Par. (Log)	*F*	*P*
CL *vs.* TL	Male *vs.* Female	a	12.256	0.0012**
		b	0.4330	0.5145
CL *vs.* CW	Male *vs.* Female	a	0.0868	0.7730
		b	1.5027	0.2438
CL *vs.* PL	Male *vs.* Female	a	---------	-------
		b	7.7304	0.0084*
CL *vs.* PH	Male *vs.* Female	a	137.8092	0.0000**
		b	0.3777	0.5425
CL *vs.* AW	Male *vs.* Female	a	124.0965	0.0000**
		b	0.4630	0.5003
CL *vs.* AL	Male *vs.* Female	a	17.8022	0.0001**
		b	0.0013	0.9715
CL *vs.* MerL	Male *vs.* Female	a	---------	--------
		b	6.3221	0.0165*
CL *vs.* CarL	Male *vs.* Female	a	20.2880	0.0011**
		b	2.4464	0.1259
CL *vs.* ProL	Male *vs.* Female	a	----------	---------
		b	15.8218	0.0007**
CL *vs.* DacL	Male *vs.* Female	a	13.6782	0.0007**
		b	3.6156	0.0657

the CL × TL relationships and CL × CW and isometry for CL × AL. In other relationships, there were different growth patterns between males and females. Males presented positive allometry for most of relationships with third pereopod articles (CL × MerL, CL × CarL, CL × DacL), while females showed isometry. On the other hand, females presented isometry for CL × PL and CL × PH, and positive allometry for CL × AW, while male presented negative allometry for all these relationships. Males presented isometry for the CL × AmL and CL × AmW relationships and decreasing ratio Am L/W. (Tab. 2, Fig. 4).

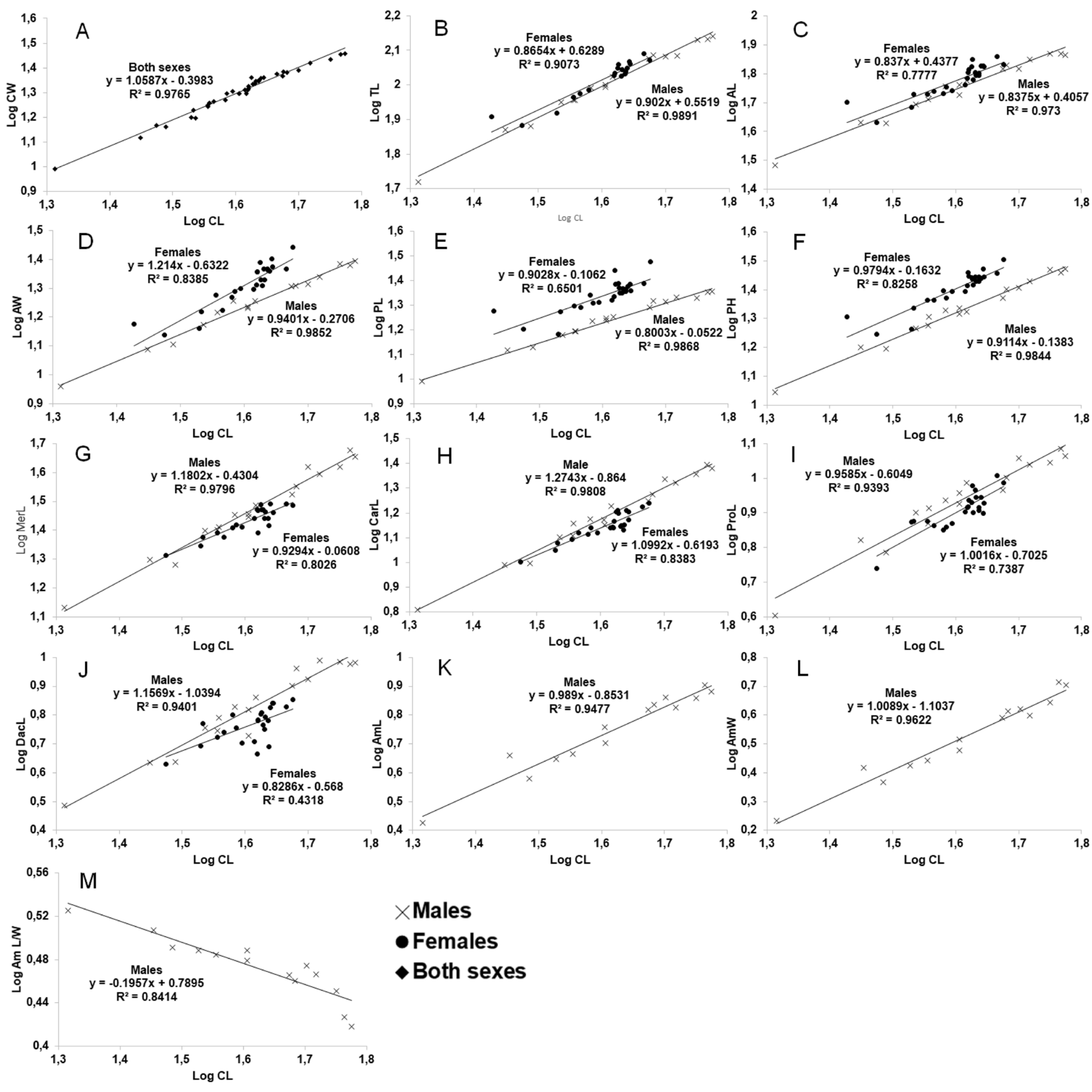

Figure 4. Comparison between morphometric relationships of males and females of *Atya gabonensis* Giebel, 1875 at the Fluvial Island Domain in the Paraíba do Sul River basin. (CL) carapace length as independent variable and the dependent variables: **A**, (CW) carapace width; **B**, (TL) total length; **C**, (AL) abdomen length; **D**, (AW) abdomen width; **E**, (PL) length of the second abdominal pleuron; **F**, (PH) height of the second abdominal pleuron; **G**, (MerL) merus length; **H**, (CarL) carpus length; **I**, (ProL) propodus length; **J**, (DacL) dactylus length; **K**, (AmL) length of male appendix interna; **L**, (AmW) width of male appendix interna; **M**, (Am L/W) male appendix interna length/width.

Table 2. Regression analyses of morphometric data of *Atya gabonensis* Giebel, 1875 at the Fluvial Island Domain in the Paraíba do Sul River basin. Carapace length (CL) is the independent variable. (PL) length of second abdominal pleuron; (PH) height of second abdominal pleuron; (CW) carapace width; (TL) total length; (AW) abdomen width; (AL) abdomen length; (MerL) merus length; (CarL) carpus length; (ProL) propodus length; (DacL) dactylus length; (AmL) length of male appendix interna; (AmW) width of male appendix interna.

Relationship	Sex	N	Intercept	Inclination	R^2	*T* (b-1)	*P*	Allometry
CL *vs.* TL	Females	25	0.6289	0.8654	0.9073	2.3375	<0.05	-
	Males	17	0.5519	0.902	0.9891	4.0065	<0.05	-
CL *vs.* CW	Both sexes	41	0.3863	1.0518	0.9766	1.9871	<0.05	+
CL *vs.* PL	Females	25	0.1062	0.9028	0.6501	0.7038	<0.05	0
	Males	17	0.0522	0.8003	0.9868	8.3612	<0.05	-
CL *vs.* PH	Females	25	0.1632	0.9794	0.8258	0.2192	<0.05	0
	Males	17	0.1383	0.9114	0.9844	2.9903	<0.05	-
CL *vs.* AW	Females	25	0.6322	1.214	0.8385	1.9262	<0.05	+
	Males	17	0.2706	0.9401	0.9852	1.9468	<0.05	-
CL *vs.* AL	Females	25	0.4377	0.837	0.7777	1.7470	<0.05	-
	Males	17	0.4057	0.8375	0.973	4.5110	<0.05	-
CL *vs.* MerL	Females	23	0.0608	0.9294	0.8026	0.7019	<0.05	0
	Males	17	0.4304	1.1802	0.9796	1.7917	<0.05	+
CL *vs.* CarL	Females	25	0.6193	1.0992	0.9808	0.9637	<0.05	0
	Males	17	0.864	1.2743	0.8383	5.9639	<0.05	+
CL *vs.* ProL	Females	25	0.7025	1.0016	0.7387	0.0126	<0.05	0
	Males	17	0.6049	0.9585	0.9393	0.6597	<0.05	0
CL *vs.* DacL	Females	25	0.568	0.8286	0.4318	0.8458	<0.05	0
	Male	17	1.0394	1.1569	0.9401	2.0812	<0.05	+
CL *vs.* AmL	Males	17	0.8531	0.989	0.9477	0.1640	<0.05	0
CL *vs.* AmW	Males	17	1.1037	1.0089	0.9622	0.1542	<0.05	0

Atya scabra

In total, 16 individuals were sampled: 8 (50 %) males and 8 (50 %) females. Carapace length of males ranging from 29.23 to 43.75 mm, with an average of 38.34 ± 10.61 mm, while that of females ranged from 8.37 to 30.09 mm, with an average of 22.06 ± 10.04 mm. The overall average was 29.19 ± 10.27 mm.

Male weight ranged from 11 to 39 g (mean = 26 ± 10.27 g), while female weight ranged from 1 to 11 g (average = 6.62 ± 3.92 g); the overall average was 16.31 ± 12.5 g. The relationships between carapace length and weight of males and females were described by the potential equations $y = 0.0123CL^{2.0247}$ and $y = 0.005CL^{2.29748}$, respectively, where y is the weight and CL is the carapace length in mm (Fig. 5).

The total length of males ranged from 78.62 to 112.64 mm, with an average of 100.40 ± 24.26 mm. Female length ranged from 31.13 to 81.12 mm, with an average of 64.95 ± 23.15 mm. The overall average was 80.46 ± 23.44 mm. The CL × TL, CL × CW, and CL × DacL relationships showed no statistically significant differences between sexes (Tab. 3). The equations that describe each of these relationships, as well as each R^2, are shown in Figure 6. Both sexes presented negative allometry for the CL × TL and CL × CW relationships and isometry for CL × ProL,

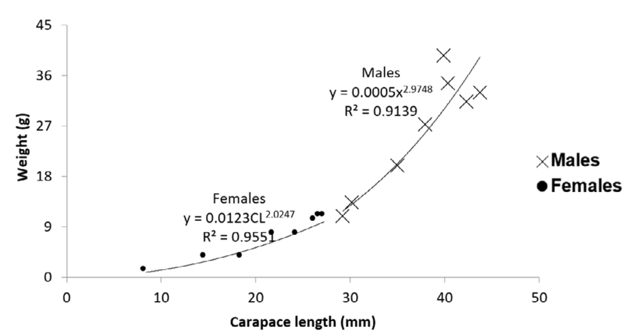

Figure 5. Relationship between carapace length and weight of *Atya scabra* (Leach, 1816) in the Fluvial Islands Domain in the Paraíba do Sul River basin.

Table 3. Results of the Covariance Analysis (ANCOVA) of morphometric data for *Atya scabra* (Leach, 1816) at the Fluvial Island Domain in the Paraíba do Sul River basin. (CL) carapace length, (PL) length of the second abdominal pleuron, (PH) height of the second abdominal pleuron, (CW) carapace width, (TL) total length, (AW) abdomen width, (AL) abdomen length, (MerL) merus length, (CarL) carpus length, (ProL) propodus length, (DacL) dactylus length. Significant difference: * P <0.05; ** P <0.01.

Relationship	Factor (Group)	Par. (Log)	F	P
CL *vs.* TL	Male *vs.* Female	A	0.5977	0.4533
		B	1.3101	0.2747
CL *vs.* CW	Male *vs.* Female	A	0.0868	0.7730
		B	1.5027	0.2438
CL *vs.* PL	Male *vs.* Female	A	22.2460	0.0004**
		B	0.3457	0.5675
CL *vs.* PH	Male *vs.* Female	A	14.9071	0.0020**
		B	0.7469	0.4043
CL *vs.* AW	Male *vs.* Female	A	23.9904	0.0003**
		B	1.7851	0.2063
CL *vs.* AL	Male *vs.* Female	A	2.0988	0.1711
		B	0.0025	0.9612
CL *vs.* MerL	Male *vs.* Female	A	6.7336	0.0249*
		B	10.4102	0.0090**
CL *vs.* CarL	Male *vs.* Female	A	6.4206	0.0278*
		B	20.2880	0.0011**
CL *vs.* ProL	Male *vs.* Female	A	1.6998	0.2189
		B	14.8744	0.0032**
CL *vs.* DacL	Male *vs.* Female	A	0.5149	0.4868
		B	0.7740	0.3978

CL × AL and CL × DacL. In other relationships, there were different growth patterns between males and females. Males presented positive allometry for CL × MerL and CL × CarL, while females presented negative allometry for the former and isometry for the second relationship. Females presented isometry for CL × PL, while males presented negative allometry for this relationship. Males presented negative allometry for the CL × AmL and CL × AmW relationships, and constant ratio Am L/W (Tab. 4, Fig. 6).

Discussion

As far as we know, the present study provides unique biological information about *A. gabonensis* on the American continent, allowing comparisons with population data from the African continent for the first time. The individuals sampled in the present study reached high values, especially of weight (a maximum of 13.7 cm in total length, with a weight of 85 g), when compared to other populations previously studied (Tab. 5). Such differences can be due to intrinsic (genetics), as well as extrinsic reasons (environmental conditions, such as food availability, temperature, etc.) (Staples and Heales, 1991; Alford and Jackson, 1993, Okayi *et al.*, 2012). The relationships between the weight and length of a species are important in determining its survival condition, providing the basis for growth and production estimates, and describing the structural characteristics of individuals in populations. In this way, our results indicate that, despite the potential anthropogenic impact, the population of *A. gabonensis* from the Fluvial Island Domain in the Paraíba do Sul River basin had a growth potential equal to or greater than other populations in Africa, showing an area of important occurrence for the maintenance of the species. Systematic analysis based on molecular data performed by two of us (CMCAO and FLM, unpublished) maintains the Amphi-Atlantic *A. gabonensis* hypothesis as well as the morphological revision of Hobbs and Hart (1982).

In the literature, there is no information on the body weight for *A. scabra*. The individuals of this species collected in the Fluvial Island Domain reached larger sizes than previously observed in other locations in Brazil. Even with considerably larger sample numbers, previous studies conducted in southern Bahia state (Almeida *et al.*, 2010; Barros *et al.*, 2020) and northern São Paulo state (Galvão and Bueno, 2000) did not find individuals with a maximum size similar to that found in the present study. Individuals with a maximum size larger than that observed in the Paraíba do Sul River were reported in Mexico by Lorán-Núñez *et al.* (2009) and reached 117 mm in total length.

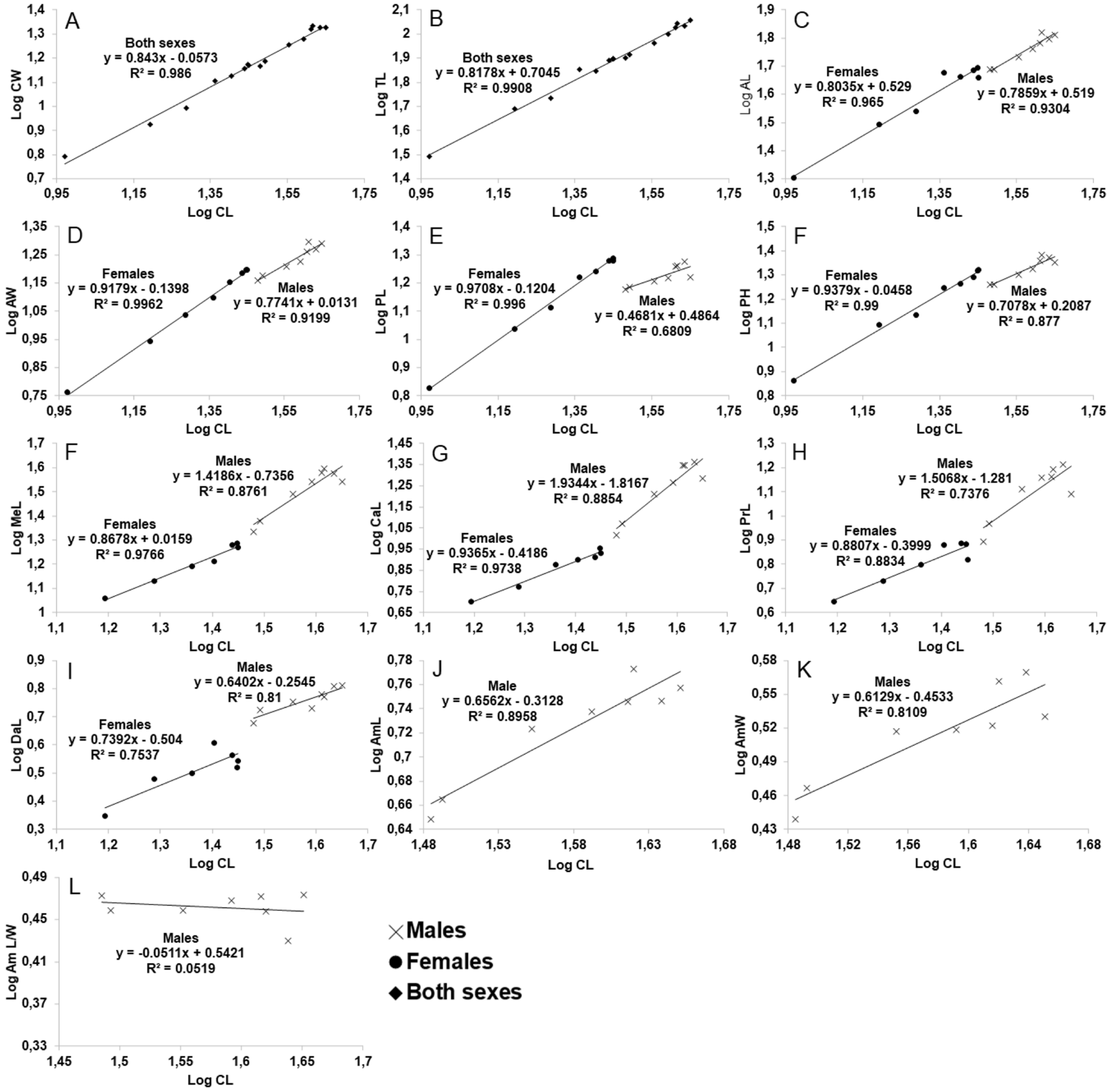

Figure 6. Comparison between morphometric relationships of males and females of *Atya scabra* (Leach, 1816) in the Fluvial Island Domain in the Paraíba do Sul River basin. (CL) carapace length as independent variable and the dependent variables: **A**, (CW) carapace width; **B**, (TL) total length; **C**, (AL) abdomen length; **D**, (AW) abdomen width; **E**, (PL) length of the second abdominal pleuron; **F**, (PH) height of the second abdominal pleuron; **G**, (MerL) merus length; **H**, (CarL) carpus length; **I**, (ProL) propodus length; **J**, (DacL) dactylus length; **K**, (AmL) length of male appendix interna; **L**, (AmW) width of male appendix interna; **M**, (Am L/W) male appendix interna length/width.

Table 4. Regression analyses of morphometric data of *Atya scabra* (Leach, 1816) in the Fluvial Island Domain in the Paraíba do Sul River basin. Carapace length (CL) is the independent variable. (PL) length of second abdominal pleuron; (PH) height of second abdominal pleuron; (CW) carapace width; (TL) total length; (AW) abdomen width; (AL) abdomen length; (MerL) merus length; (CarL) carpus length; (ProL) propodus length; (DacL) dactylus length; (AmL) length of male appendix interna; (AmW) width of male appendix interna.

Relationship	Sex	N	Intercept	Inclination	R^2	*T* (b-1)	*P*	Allometry
CL *vs.* TL	Both sexes	16	0.7045	0.8178	0.9908	8.6273	<0.05	-
CL *vs.* CW	Both sexes	16	0.0573	0.843	0.986	5.8462	<0.05	-
CL *vs.* PL	Females	8	0.1204	0.9708	0.996	1.1654	<0.05	0
	Males	8	0.4864	0.4681	0.6809	4.0657	<0.05	-
CL *vs.* PH	Females	8	0.0458	0.9379	0.99	1.6163	<0.05	0
	Males	8	0.2087	0.7078	0.877	2.7007	<0.05	-
CL *vs.* AW	Females	8	0.1398	0.9179	0.9962	3.5348	<0.05	-
	Males	8	0,0131	0.7741	0.9199	2.4226	<0.05	-
CL *vs.* AL	Both sexes	16	0.6268	0.723	0.9685	7.9474	<0.05	0
CL *vs.* MerL	Females	7	0.0159	0.8678	0.9766	2.2015	<0.05	-
	Males	8	0.7356	1.4186	0.8761	1.9216	<0.05	+
CL *vs.* CarL	Females	7	0.4186	0.9365	0.9738	0.9243	<0.05	0
	Males	8	1.8167	1.9344	0.8854	3.2892	<0.05	+
CL *vs.* ProL	Females	7	0.3999	0.8807	0.8834	0.8335	<0.05	0
	Males	8	1.281	1.5068	0.7376	1.3814	<0.05	0
CL *vs.* DacL	Both sexes	15	0.8705	1.0202	0.9098	0.2266	<0.05	0
CL *vs.* AmL	Males	8	0.3128	0.6562	0.8958	3.7620	<0.05	-
CL *vs.* AmW	Males	8	0.4533	0.6129	0.8109	3.2031	<0.05	-

Males of both species had relatively larger articles of the third pereopod when compared to females. Almeida *et al.* (2010) also detected a difference in the growth of the merus of the third pereopod in *A. scabra*. Sexual dimorphism in chelipeds has been widely reported in caridean shrimp, as such structures are involved in agonistic disputes between males, territories, and females for mating (Bauer, 2004). However, there is no information whether the third pereopod can be used for such purposes in *Atya*. The third pair of pereopods is used by shrimps of this genus to attach themselves to the substrate (usually rocky) in strong water flow environments or waterfalls, preventing the animal from being carried away by the stream while performing particle filtration (Fryer, 1977; Villalobos and Álvarez, 1997).

Females, on the other hand, showed greater abdominal growth than males, with greater abdomen width and length as well as greater length and height of the second abdominal pleura. These characteristics were observed for the two studied species, being adaptations to increase egg hatching area and, consequently, fecundity, and useful for the detection of morphological sexual maturity size in females in future studies (Mantelatto and Barbosa, 2005; Pralon and Negreiros-Fransozo, 2006; Pantaleão *et al.*, 2012).

For both species, there was no difference between males and females in the relationship between carapace length and width, although *A. gabonensis* presented positive allometry for this relationship and *A. scabra* showed negative allometry. A similar allometric pattern for this species was observed by Barros *et al.* (2020), in Contas River, Bahia state, although the authors have detected differences between sexes in the slope and in the intercept for this relationship. Such difference gives *A. gabonensis* a more robust appearance when compared to *A. scabra*, the former being considered the largest species of the genus and more attractive for aquarists. For both sexes, of both species, negative allometry was observed in the correlations between the carapace and total length and abdomen length. Both species suffer fishing pressure in certain localities, and larger individuals reach higher prices, although our results indicate that in larger sizes, these animals have lower meat yields in relation to their total size. Lima *et al.* (2018) observed a reduction

Table 5. Minimum, maximum and mean values ± standard deviation of total length (mm) and weight (g) of *Atya gabonensis* Giebel, 1875 and *Atya scabra* (Leach, 1816), obtained in different locations, available in previous studies and the present study.

	Locality	Sex	Total length range (mm)		Mean ± S.D.	Weight range (g)		Weight range ± S.D.	Reference
			Min	Max		Min	Max		
Atya gabonensis	Cross River, Itigidi, Nigeria	Not determined	65	140	-	8.1	60.3	-	Nwosu (2009)
	Mu River, Makurdi, Nigeria	Not determined	50	122	79.9 ± 21.2	3.3	51.6	13.98 ± 10.36	Okayi and Iorkyaa (2004)
	Benue River, Nigeria	Females	32	105	-	3.2	34	-	Obande *et al.* (2009)
	Bandama River, N´Douci, Ivory Coast	Males	81	138	-	11.68	86.8	40.89 ± 15.47	Madelaine *et al.* (2015)
		Females	73	129	-	11.35	47.5	23.79 ± 5.62	
	Paraíba do Sul River, Brazil	Males	51.4	137.6	103.0 ± 24.1	3	85	35.6 ± 26.1	Present study
		Females	75.6	124.1	102.5 ± 12.0	8	44	26.7 ± 18.7	
Atya scabra	Santana River, Ilhéus, Brazil	Males	14.98	88.77	-	-	-	-	Almeida *et al.* (2010)
		Females	29.03	64.4	-	-	-	-	
	Guaecá River, São Sebastião, Brazil	Males	22.7	89.3	54.5 ± 13.5	-	-	-	Galvão and Bueno (2000)
		Females	25.3	61.1	46.9 ± 6.8	-	-	-	
	Los Pescados River, Mexico	Males	48	117	90.75 ± 11.26	-	-	-	Lorán-Núñez *et al.* (2009)
		Females	32	103	68.67 ± 7.22	-	-	-	
	Actopan River, Mexico	Males	54	105	78.93 ± 10.23	-	-	-	
		Females	38	88	65.28 ± 7.12	-	-	-	
	São Sebastião Island, Brazil	Females	42.8	77.3	-	-	-	-	Herrera-Correal *et al.* (2013)
	Contas River, Brazil	Males	37.45	96.6	73.04 ± 10.83	-	-	-	Barros *et al.* (2020)
		Females	38.0	87.4	57.65 ± 8.65	-	-	-	
	Paraíba do Sul River, Brazil	Males	78.62	112.64	100.4 ± 24.26	11	39	26.0 ± 10.27	Present study
		Females	31.13	81.12	64.95 ± 23.15	1	11	6.62 ± 3.92	

in meat yield with increasing size of individuals from the Amazon River in *Macrobrachium amazonicum* (Heller, 1862). *Atya* species are used as a protein source by riverine human populations and, although informal trade for food is reported, this is at a smaller scale when compared to other species, such as those of the genus *Macrobrachium*, with a focus on subsistence artisanal fishing (Oliveira, 1945; Holthuis, 1980; Hobbs and Hart, 1982; Almeida *et al.*, 2010).

The male appendix interna showed differences in the growth pattern between the two species. *Atya gabonensis* presented isometry for both width and length, while *A. scabra* presented negative allometry for both relationships. For *A. gabonensis*, the male appendix interna length × width ratio decreases along with animal growth, *i.e.*, such structures becomes proportionally wider in larger individuals. In *A. scabra*, on the other hand, such relationships remained constant in all sizes analysed. Thus, this presents another distinctive characteristic for the two species.

This study presents previously unpublished morphometric aspects of both species for the Paraiba do Sul River Basin, as well as the first information on the biology of *A. gabonensis* on the American continent and *A. scabra* for the state of Rio de Janeiro, Brazil. The maximum sizes reached by both species and its relationship with weight indicate the Fluvial Island Domain as an important area for the maintenance of population stocks of these species, which may act as a source of individuals for other regions. Furthermore, such populations are still viable in this area due to the fact that the estuary is not fragmented by dams, which enables the juvenile recruitment of these populations. In both species, males showed a larger relative growth of the third pereopod articles while females had a larger growth of the abdomen. Moreover, morphometric differences between the species were found, even for CL × CW and for male appendix interna growth. Such knowledge about the basic biology and morphology of these species may serve as a basis for future genetic population assessments and the establishment of conservation management policies for the region, and as evaluations of the conservation status of these species, whose habitats suffer from anthropogenic pressures.

Acknowledgments

We thank the members of LBSC (Alvaro Costa, Edvanda Carvalho, Elis Mesquita, Natalia Rossi and Rafael Robles), the Piabanha Project team (Thiago Berriel, Christian Natalia, Evodio Peçanha, Adam Carvalho, Andreza Pacheco, Dominguinhos Afonso, João Lucas and Jacson Gomes), CEPTA/ICMBIO (Luis Gaspar, Noel Martins and Sandoval Santos Jr.), PESAGRO-RIO and MZUSP for their assistance in specimen collection. FLM expresses sincere thanks to the National Council for Scientific and Technological Development – CNPq (Proc. 473050/2007-2, 302748/2010-5, 304968/2014-5, 302253/2019-0 and 471011/2011-8) and the São Paulo Research Foundation - FAPESP (Temáticos BIOTA Proc. 2010/50188-8 and INTERCRUSTA 2018/13685-5) for financial support during collection and analysis activities. FLC thanks CEPTA/ICMBIO for their assistance in the collections carried out under Project UNDP - BRA/08/023 and to CNPq (Proc. 425769/2016-0). We are thankful to the anonymous reviewers for constructive and useful comments during the reviewing process.

References

Alford, R.A. and Jackson, G.D. 1993. Do cephalopods and larvae of other taxa grow asymptotically? *The American Naturalist*, 141: 717–728.

Almeida, A.O.; Mossolin, E.C. and Luz, J.R. 2010. Reproductive biology of the freshwater shrimp *Atya scabra* (Leach, 1815) (Crustacea: Atyidae) in Ilhéus, Bahia, Brazil. *Zoological Studies*, 49: 243–252.

Barros, M.S.F.; Calado, T.C.S; Santos, E.V.; Silva, A.S. and Albuquerque, L.G.A. 2020. Population biology and sexual dimorphism in the freshwater prawn *Atya scabra* (Decapoda: Atyidae) in the Contas River, Bahia, Brazil. *Revista de Biologia Tropical*, 68: 743–751.

Bauer, R.T. 2004. Remarkable shrimps: adaptations and natural history of the carideans. Animal Natural History Series, University of Oklahoma Press, Norman, 282p.

Bauer, R.T. 2013. Amphidromy in shrimps: a life cycle between rivers and the sea. *Latin American Journal of Aquatic Research*, 41: 633–650.

Bizerril, C.R.S.F. 1998. A ictiofauna: diversidade biológica e padrões biogeográficos. p. 15–48. In: C.R.S.F. Bizerril; L.M.N. de Araújo and P.C. Tosin (eds), Contribuição ao conhecimento da bacia do rio Paraíba do Sul: coletânea de Estudos. ANEEL/CPRM, Rio de Janeiro.

Carvalho-Batista, A.; Carvalho, F.L.; Souza, G. and Mantelatto, F.L. 2019. Parâmetros populacionais do camarão *Macrobrachium carcinus* (Linnaeus 1758) (Palaemonidae) no Domínio das Ilhas Fluviais na bacia do rio Paraíba do Sul. p. 374–393. In: T.C.S. Berriel; E. P. Caramaschi and C.N.M. Polaz (eds), Monitoramento da fauna aquática: Funções ecossistêmicas do domínio das ilhas fluviais do rio Paraíba do Sul. Projeto Piabanha, Itaocara, Rio de Janeiro.

Carvalho, F.L.; Souza, G. and Mantelatto, F.L. 2019. Camarões e caranguejos de água doce no trecho médio e baixo da bacia do rio Paraíba do Sul. p. 160–178. In: T.C.S. Berriel; E.P. Caramaschi and C.N.M. Polaz (eds), Monitoramento da fauna aquática: funções ecossistêmicas do domínio das ilhas fluviais do rio Paraíba do Sul. Projeto Piabanha, Itaocara, Rio de Janeiro.

Cavadas-Barcellos, F.; Acselrad, M.V. and Costa, V.C. 2011. Efetividade na aplicação de recursos obtidos com a cobrança pelo uso da água bruta na porção fluminense da Bacia do Paraíba do Sul. *Revista Iberoamericana de Economía Ecológica*, 16/17: 1–15.

Chace, F.A. 1972. The shrimps of the Smithsonian-Bredin Caribbean Expeditions with a summary of the West Indian shallow-water species (Crustacea: Decapoda: Natantia). *Smithsonian Contributions to Zoology*, 98: 1–179.

Dantas, M.E.; Shinzato, E.; Medina, A.I.M.; Silva, C.R.; Pimentel, J.; Lumbreras, J.F. and Calderano, S.B. 2000. Diagnóstico geoambiental do estado do Rio de Janeiro. Companhia de Pesquisa de Recursos Minerais, Serviço Geológico do Brasil, Departamento de Gestão Territorial e Departamento de Informações Institucionais, Rio de Janeiro, Brasil, 33p.

Devide, A.C.P.; Castro, C.M.; Ribeiro, R.L.D.; Abboud, A.C.S.; Pereira, M.G. and Rumjanek, N.G. 2014. História ambiental do Vale do Paraíba Paulista, Brasil. *Revista Biociências*, 20: 12–29.

Fonseca, K.M.L.; Ostrovski, M.C. and Silva-Ferreira, T.C.G. 1994. Ocorrência de *Atya gabonenses* Giebel, 1875 (Crustacea: Decapoda: Atyidae) na bacia do rio Paraíba do Sul, estado do Rio de Janeiro, Brasil. *Nauplius*, 2: 129–130.

Fryer, G. 1977. Studies on the functional morphology and ecology of atyid prawns in Dominica. *Philosophical Transactions of the Royal Society B*, 277: 57–129.

Galvão, R. and Bueno, S.L.S. 2000. Population structure and reproductive biology of the camacuto shrimp, *Atya scabra* (Decapoda, Caridea, Atyidae), from São Sebastião, Brazil. *Crustacean Issues*, 12: 291–299.

Herrera-Correal, J.; Mossolin, E.C.; Wehrtmann, I.S. and Mantelatto, F.L. 2013. Reproductive aspects of the caridean shrimp *Atya scabra* (Leach, 1815) (Decapoda: Atyidae) in São Sebastião Island, southern Atlantic, Brazil. *Latin American Journal of Aquatic Research*, 41: 676–684.

Hobbs, H.H. 1980. *Atya gabonensis* (Decapoda, Atyidae) in the western hemisphere. *Crustaceana*, 38: 111.

Hobbs, H.H. and Hart, C.W. 1982. The shrimp genus *Atya* (Decapoda: Atyidae). *Smithsonian Contributions to Zoology*, 364: 1–143.

Holthuis, L.B. 1980. FAO Species Catalogue. Shrimps and prawns of the world: an annotated catalogue of species of interest to fisheries. *FAO Fisheries Synopsis*, 1(125): 1–271.

Kadjo, V.; Etchian, O.A.; Ble, C.M.; Soro, D.; Yapi, J.N. and Otchoumou, A. 2016. Caractérisation de la pêche aux crevettes d'eau douce *Atya scabra* (Leach, 1815) (Decapoda: Atyidae) dans la rivière Bia, Côte d'Ivoire. *International Journal of Biological and Chemical Sciences*, 10: 620–631.

Lima, J.F.; Duarte, S.S. and Damasceno, L.F. 2018. Relações biométricas e rendimentos de carne e resíduos de camarão-da-amazônia capturado na foz do rio Amazonas. *Embrapa Amapá - Boletim de Pesquisa e Desenvolvimento*, 18: 1–19.

Lipták, B. and Vitázková, B. 2015. Beautiful, but also potentially invasive. *Ekológia*, 34: 155–162.

Lorán-Núñez, R.M.; Valdéz-Guzmán, A.J. and Martínez-Isunza, R. 2009. Estudio biológico-pesquero del "burro" *Atya scabra* en el río Los Pescados y río Actopan, Veracruz, México. *Ciencia Pesquera*, 17: 5–16.

Madeleine, K.A.M.; Gervais, N.K. and Gouli G.B. 2015. Weight-length relationships and condition factor of *Atya gabonensis* Giebel, 1875 in Bandama River – Côte d'Ivoire. *International Journal of Fisheries and Aquatic Studies*, 3: 283–286.

Mantelatto F.L. and Barbosa, L.R. 2005. Population structure and relative growth of freshwater prawn *Macrobrachium brasiliense* (Decapoda, Palaemonidae) from São Paulo State, Brazil. *Acta Limnológica Brasiliensis*, 17: 17–24.

Mantelatto, F.L.; Torati, L.S.; Pileggi, L.G.; Mossolin, E.C.; Terossi, M.; Carvalho, F.L.; Rocha, S.S. and Magalhães, C. 2016. Avaliação dos Camarões Atiídeos (Decapoda: Atyidae). p. 93-102. In: M. Pinheiro and H. Boos (eds), Livro Vermelho dos Crustáceos do Brasil: Avaliação 2010-2014. Porto Alegre, Rio Grande do Sul, Sociedade Brasileira de Carcinologia.

Marengo, J.A., and Alves, L.M. 2005. Tendências hidrológicas da bacia do rio Paraíba do Sul. *Revista Brasileira de Meteorologia*, 20: 215–226.

McDowall, R.M. 2007. On amphidromy, a distinct form of diadromy in aquatic organisms. *Fish and Fisheries*, 8: 1–13.

Melo, A.G. 2003. Manual de identificação dos Crustacea Decapoda de água doce do Brasil. São Paulo, Edições Loyola/FAPESP, 430p.

Moraes, M.B.; Polaz, C.N.M.; Caramaschi, E.P.; Santos-Junior, S.; Souza, G. and Carvalho, F.L. 2017. Espécies exóticas e alóctones da bacia do rio Paraíba do Sul: implicações para conservação. *Biodiversidade Brasileira*, 7: 34–54.

Motoh, H. and Murai, T. 2006. On the edible crustaceans of Guinea, eastern Central Atlantic. *Cancer*, 16: 27–36.

Nwosu, F.M. 2009. Aspects of biology of the Gabon shrimp *Atya gabonensis,* Giebel, 1875 in the Cross River, Nigeria. *Journal of Fisheries International,* 4: 58–61.

Obande, R.A. and Kusemiju, K. 2008. Food and feeding habits of *Atya gabonensis* from lower river Benue in Northern Nigeria. *West African Journal of Applied Ecology,* 13: 77–82.

Obande, R.A.: Kusemiju, K. and Egonwon, R. 2009. Fecundity and gonadal development of *Atya gabonensis* from lower river Benue in northern Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 1: 68–74.

Okayi, R.G.; Ataguba, G.A. and Mbata, F.U. 2012. Stock assessment of shrimps and prawn species of the lower Benue and Niger river, Nigeria. *E3 Journal of Agricultural Research and Development*, 2: 92–95.

Okayi, G. and Iorkyaa, A. 2004. Length-weight relationship and condition of freshwater shrimps *Atya gabonensis* and *Macrobrachium felicinium* from the Mu River, Macurdi, Nigeria. *Animal Research International*, 1: 153–159.

Oliveira, C.M.C.A; Terossi, M. and Mantelatto, F.L. 2019. Phylogeographic structuring of the amphidromous shrimp *Atya scabra* (Crustacea, Decapoda, Atyidae) unrevealed by range-wide mitochondrial DNA sampling. *Marine and Freshwater Research*, 70: 1078–1093.

Oliveira, L.P.H. 1945. Verificação da existência de *Atya scabra* Leach, camarão de água doce da família Atyidae, Crustacea, no nordeste do Brasil. *Memórias do Instituto Osvaldo Cruz*, 43: 178–190.

Page, T.J.; Cook, B.D.; von Rintelen, T.; von Rintelen, K. and Hughes, J.M. 2008. Evolutionary relationships of atyid shrimps imply both ancient Caribbean radiations and common marine dispersals. *Journal of the North American Benthological Society*, 27: 68–83.

Pantaleão, J.A.F.; Hirose G.L. and Costa, R.C. 2012. Relative growth, morphological sexual maturity, and size of *Macrobrachium amazonicum* (Heller 1862) (Crustacea, Decapoda, Palaemonidae) in a population with an entirely freshwater life cycle. *Invertebrate Reproduction and Development*, 56: 180–190.

Polaz, C.N.M.; Bataus, Y.S.L; Desbiez, A. and Reis, M.L. 2011. Plano de ação nacional para a conservação das espécies aquáticas ameaçadas de extinção da bacia do rio Paraíba do Sul. Brasília, Instituto Chico Mendes de Conservação da Biodiversidade, ICMBio, 140p. (Série Espécies Ameaçadas, 16)

Pralon, B.G.N. and Negreiros-Fransozo, M.L. 2006. Population biology of *Palaemon* (*Palaeander*) *northropi* Rankin, 1898 (Crustacea, Decapoda, Palaemonidae) in a tropical South American estuary. *Acta Limnologica Brasiliensis*, 18: 77–87.

Ramos-Porto, M. and Coelho, P.A. 1998. Malacostraca Eucarida. Caridea (Alpheoidea excluded). p. 325–350. In: P.S. Young (ed.), Catalogue of Crustacea of Brazil. Rio de Janeiro, Museu Nacional. (Série Livros, 6).

Souza, G.; Daudt, L.F.O.; Souza, C.N.S.; Nascimento, A. and Reis, W.S. 2007. Diagnóstico da cadeia produtiva pesqueira do município de Itaocara. Relatório Técnico Final, Projeto Piabanha. Rio de Janeiro, Itaocara, 55p.

Staples, D.J. and Heales, D.S. 1991. Temperature and salinity optima for growth and survival of juvenile banana prawns *Penaeus merguiensis*. *Journal of Experimental Marine Biology and Ecology*, 154: 251–274.

Villalobos, J.L. and Álvarez, F.1997. Atyidae (burritos, camaroncitos). p. 401–403. In: *E.G.* Soriano; R. Oirzo and R.C. Vogt (eds), Historia Natural de Los Tuxtlas. Ciudad de Mexico, Universidad Nacional Autónoma de México, Instituto de Biología.

von Rintelen, K.; Page, T.J.; Cai, Y.; Roe, K.; Stelbrink, B.; Kuhaja, B.R.; Iliffe, T.M.; Hughes, J. and von Rintelen, T. 2012. Drawn to dark side: A molecular phylogeny of freshwater shrimps (Crustacea: Decapoda: Caridea: Atyidae) reveals frequent cave invasions and challenge current taxonomic hypothesis. *Molecular Phylogenetics and Evolution*, 63: 82–96.

Weiperth, A.; Gál, B.; Kuříková, P.; Langrová, I.; Kouba, A. and Patoka, J. 2019. Risk assessment of pet-traded decapod crustaceans in Hungary with evidence of *Cherax quadricarinatus* (von Martens, 1868) in the wild. *North-Western Journal of Zoology*, 15: 42–47.

Werner, U. 2003. Shrimps, crayfishes, and crabs in the freshwater aquarium. Aqualog, Rodgau, Aquaristik - Consulting and Service GmbH, 48p.

Zar, J.H. 1999. Biostatistical Analysis. Fourth edition. London, Prentice Hall, 663p.