



***Macrobrachium amazonicum* (Crustacea: Decapoda: Palaemonidae) shows a polyphasic growth pattern in the Lower São Francisco River, Northeastern Brazil**

RAFAEL BARROS DE CASTRO¹, ANNA KAROLINE AZEVEDO FARIAS¹ & VICTOR EMMANUEL LOPES DA SILVA²

¹ Federal University of Alagoas, Carcinology Laboratory - Marine and Natural Sciences Laboratories - Maceió, Alagoas, Brasil

² Federal University of Alagoas, Ecology, Fish and Fisheries Laboratory - Institute of Biological and Health Sciences, Maceió, Alagoas, Brasil.

*Corresponding author: rafaelbarros1@gmail.com

Abstract. We modeled carapace length in relation to species total length using two distinct methods: the power function of Huxley and an expansion of this method. We found evidence that *Macrobrachium amazonicum* has a polyphasic allometry and growth pattern may be associated to species reproduction.

Key words: Amazon River prawn; relative growth; Huxley function; size at the onset of sexual maturity

Resumo: *Macrobrachium amazonicum* (Crustacea: Decapoda: Palaemonidae) mostra um padrão de crescimento polifásico no baixo rio São Francisco, nordeste do Brasil. Modelamos o comprimento da carapaça em relação ao comprimento total da espécie utilizando dois métodos distintos: a função potência de Huxley e uma expansão deste método. Encontramos evidências de que os camarões possuem alometria polifásica e o padrão de crescimento pode estar associado à reprodução das espécies

Palavras-chave: Camarão amazônico; crescimento relativo; Função de Huxley; início da maturidade sexual.

The Amazon River prawn *Macrobrachium amazonicum* (Heller 1862) was introduced in the northeastern Brazil in the 1940's by the Fishery Services of the National Department of Services Against Droughts (DNOCS) (Sampaio *et al.* 2007). Due its fast reproduction and acclimatization, the species quickly spread to several rivers, streams and estuaries, becoming one of the most important fishery resources in the region (Maciel & Valenti 2009). Yet, information concerning the biological parameters of *M. amazonicum* for the northeastern Brazil is very limited (Chong-Carrillo *et al.* 2015), even in highly productive ecosystem.

In the Lower São Francisco River, for example, there is no available data on the population structure of the Amazon River prawn, not even for

basic information such as its growth characteristics. Growth data is extremely important for the proper management of species, and its usually the first step in population dynamic studies, as well as in stock assessment and monitoring (Ra'anan *et al.* 1991). In this respect, the presently reported study was intended to contribute to the current knowledge on the Amazon River prawn by providing new data on the relative growth of this species from the Lower São Francisco River in the northeastern Brazil.

The Lower São Francisco River runs 265 km through the states of Bahia, Pernambuco, Sergipe and Alagoas before emptying into the Atlantic Ocean. Twelve sampling stations were established throughout the river up to the estuary mouth (Fig. 1), and specimens of *M. amazonicum* were sampled

twice a year from April 2008 to October 2010 with a trawl net (8 m long and 1 m high with mesh size of 2 mm) operated by local fishermen. All collected individuals were stored in ice and taken to the laboratory where individuals were identified at species level according to Melo (2003). Each specimen had its carapace length (CL) and total length (TL) registered in millimeters (mm) with a digital caliper with 0.01 of precision, following the morphometric description of Primavera and Quintio (2000).

To analyze the relative growth of *M. amazonicum*, we followed the adapted methodology of Bervian *et al.* (2006), which expands the Huxley's growth model (Huxley 1924) by assuming that the growth process can't always be described by a linear fit. Therefore, we first modeled growth for females and males as linear functions by fitting two models between TL and CL using the Huxley's equation for each sex: one using the individual measurements of all specimens, and a second one using data grouped into TL size-classes of 1 mm. Standard residuals of fitted models were plotted against CL data to test the existence of a uniphase (constant) vs. a polyphasic growth pattern, and the allometric coefficient of each size class was isolated (bsc) and also plotted against CL to identify whether the power function had the best fit for the data.

Once a non-linear pattern for both sexes was identified by the two approaches applied, we performed a third-degree polynomial adjustment to the bsc and CL relationship following recommendations of Bervian *et al.* (2006). The first derivative of the polynomial function was used to describe the growth pattern of *M. amazonicum* and changing points in its growth stanzas were estimated by assuming y as 0, and isolating x values in the first derivative equation. All analyses were carried out in the software R statistics v.3.5.1. at a significance level of 0.05 (R Core Team 2018).

A total of 211 specimens of *M. amazonicum* were collected during the study period, with 106 of these individuals being females and 104 being males. The Huxley equation showed a good fit between the total length (TL) and carapace length (CL) (Figs. 2a-3a, $p < 0.05$, $r^2 = 0.95$), however, the analysis of residuals from models fitted using this equation indicated that the power function could not explain the whole data distribution for both sexes as shown by the non-random fit of residuals (Figs 2b-3b). Moreover, the isolated allometric coefficient for each size class (bsc) showed a non-linear pattern in

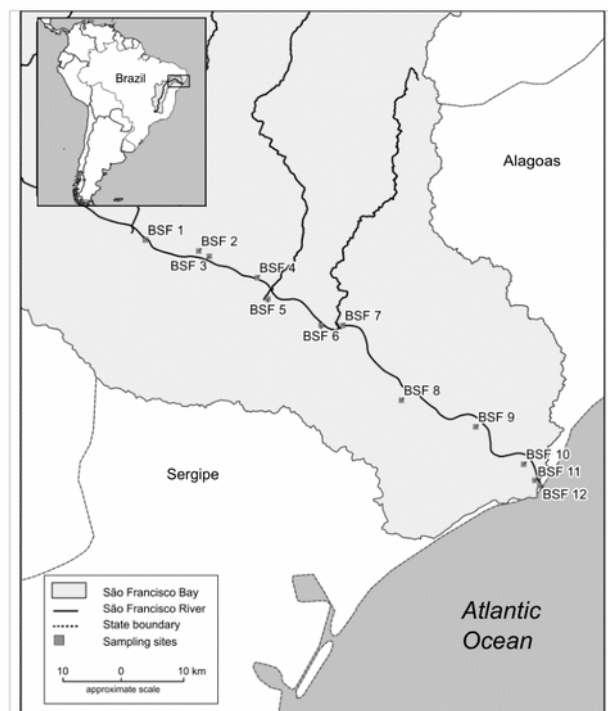


Figure 1. Map of the study area established throughout the Lower São Francisco River.

growth, with bsc fluctuating in relation to size for females and males (Figs. 2c-3c).

The third-degree polynomial adjustment made in the bsc and CW relationship produced a better fit for the data and allowed us to identify two changing points in growth stanzas (Figs 2d-3d, $p < 0.05$, $r^2 = 0.99$), showing that *M. amazonicum* has a polyphasic growth pattern. Specifically, these results show that the relative growth of female and male individuals of *M. amazonicum* in the Lower São Francisco River could not be fully described as a uniphase model, indicating that the investments in growth of this species changes throughout its development. There are many internal and external factors that can affect the growth of species in nature and cause these changes in investments and patterns, such as fluctuations of environmental conditions, variability in productivity levels of ecosystems and the ontogenetic development of individuals (Chen & Chen 2003).

The first change in growth stanza identified for the Amazon River prawn happened at similar sizes for both sexes, with females' changing point being slightly greater than males ($\bar{x} = 15.35$; $\sigma = 14.17$). These estimated sizes are close to the ones that have been reported in literature as the length where the functional gonad maturation of this

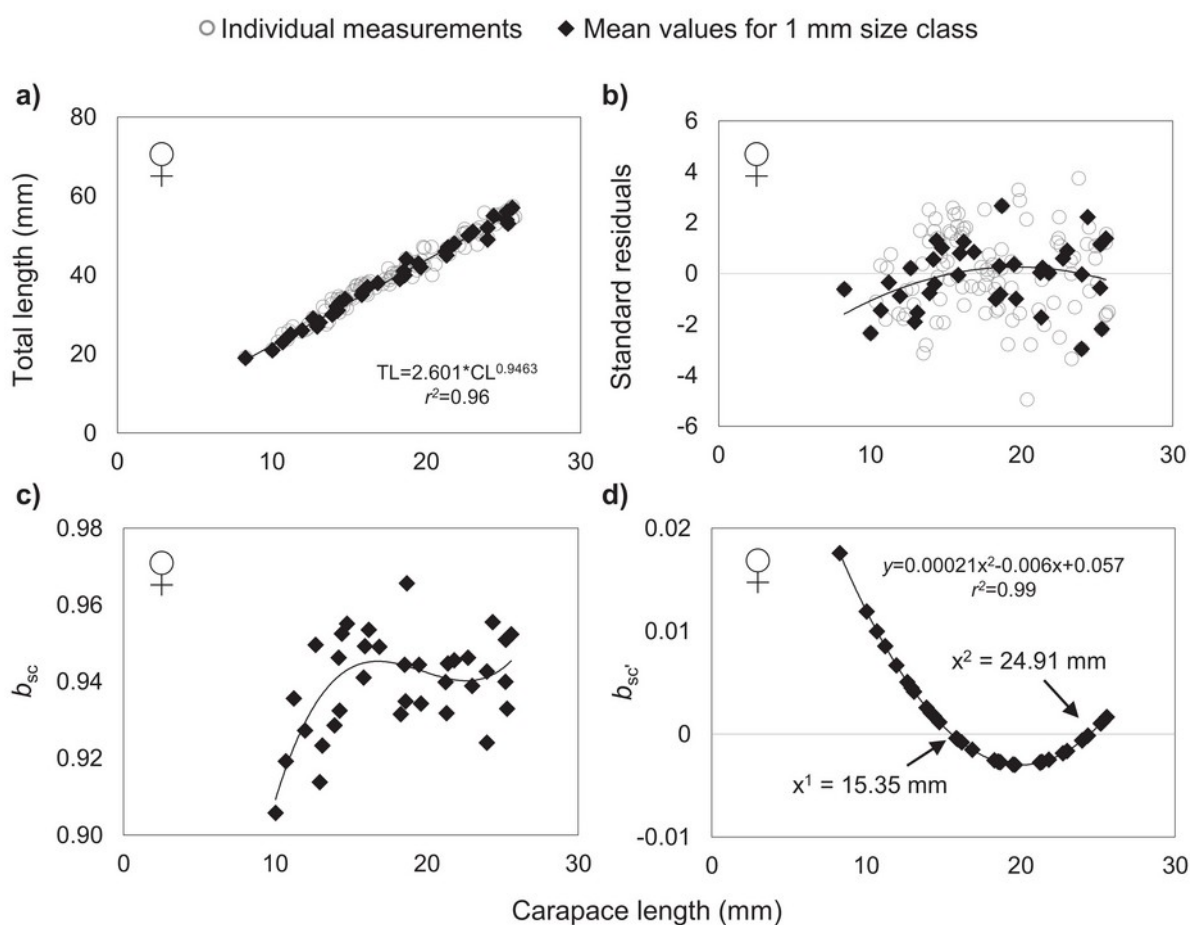


Figure 2. Relative growth of female individuals of *Macrobrachium amazonicum* in the Lower São Francisco River. **a)** relationship between total length (TL) and carapace length (CL) estimated by the allometric equation of Huxley (1924); **b)** standardized residuals plotted against CL values; **c)** distribution of isolated allometry coefficient for size classes (b_{sc}) against CL (trend line described by the third-degree polynomial function); **d)** first derivative of the polynomial function used to describe the growth of *Macrobrachium amazonicum* females and its stanzas changing point.

species occurs in the Southern Brazil (Paschoal & Zara 2020), which can indicate that changes in growth of *M. amazonicum* are related to the reproductive cycle of this species. Specifically, the first changing point may suggest that once sexual maturity is reached, *M. amazonicum* starts to invest more in reproduction than growth, altering its growth rate and creating a new growth pattern. Changes in energy allocation are well-described for many species (Paschoal *et al.* 2013), including for the Amazon River prawn (Paschoal & Zara 2018), and not only provide a better understanding of species' life cycle, but also represent an important information about its well-being.

A second changing point in growth was identified for both sexes, indicating that energy allocation to growth is kept even after maturity. Although some taxa may stop the growth investment

once they reach maturity, most prawn species continue to grow as a strategy to enhance reproductive success (Bauer 2004). For instance, in the Lower São Francisco River, although females and males appear to reach maturity at similar sizes, the second change in growth occurred at different lengths, with the carapace length (CL) growing larger in females ($\varphi = 24.91$ mm). This result may suggest that male individuals of *M. amazonicum* stop investing in growth at smaller sizes ($\sigma = 21.06$ mm), which can be related to greater energy allocation to reproductive activities, such as spermatozooids production (Bauer 2004, Paschoal & Zara 2018). The larger CL in females may also indicate a strategy to achieve success in reproduction by increasing fecundity rate and enhancing eggs protection (Bauer 2004).

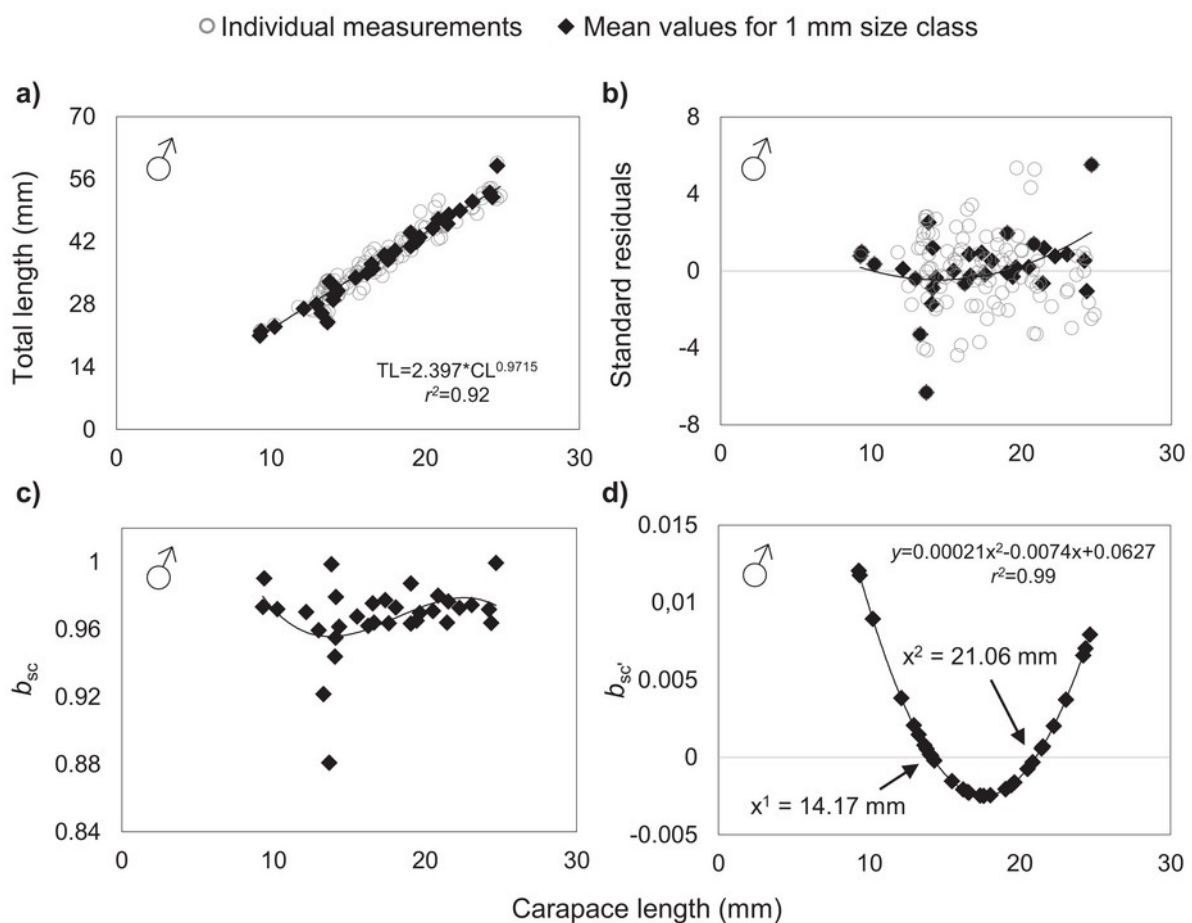


Figure 3. Relative growth of male individuals of *Macrobrachium amazonicum* in the Lower São Francisco River. **a)** relationship between total length (TL) and carapace length (CL) estimated by the allometric equation of Huxley (1924); **b)** standardized residuals plotted against CL values; **c)** distribution of isolated allometry coefficient for size classes (b_{sc}) against CL (trend line described by the third-degree polynomial function); **d)** first derivative of the polynomial function used to describe the growth of *Macrobrachium amazonicum* males and its stanzas changing point.

Our study provides new information on the relative growth of *M. amazonicum* for the northeastern Brazil, showing that the species has a polyphasic allometry in the region. We also highlight that growth patterns of this species could be associated to its reproductive cycle, especially to sexual maturity and reproductive success.

References

- Bauer, R. T. 2004. **Remarkable shrimps: Adaptations and natural history of the carideans.** University Oklahoma Press, Oklahoma, USA.
- Bervian, G., Fontoura N. F. & Haimovici, M. 2006. Statistical model of variable allometric growth: otolith growth in *Micropogonias furnieri* (Actinopterygii, Sciaenidae). **Journal of Fish Biology**, 68:196–208.
- Bueno, A. A. P., Bonatto, C. R. & Almeida, A. C. 2019. Influence of environmental variables on seasonal abundance and relative growth of *Macrobrachium amazonicum* (Crustacea: Decapoda: Caridea): variations of a continental population. **Iheringia. Série Zoologia**, 109:1–9.
- Chen, S. M. & Chen, J. C. 2003. Effects of pH on survival, growth, molting and feeding of giant freshwater prawn *Macrobrachium rosenbergii*. **Aquaculture**, 218:613–623.
- Chong-Carrillo, O., Vega-Villasante, F., Arencibia-Jorge, R., Akintola, S. L., Michán-Aguirre, L. & Cupul-Magaña, F. G. 2015. Research on the river shrimps of the genus *Macrobrachium* (Bate, 1868) (Decapoda: Caridea: Palaemonidae) with known or potential economic importance: Strengths and

- weaknesses shown through scientometrics. **Latin American Journal of Aquatic Research**, 43:684–690.
- Huxley, J. S. 1924. Constant differential growth-ratios and their significance. **Nature**, 114:895–896.
- Maciel, C. & Valenti, W. 2009. Biology, fisheries, and aquaculture of the Amazon River prawn *Macrobrachium amazonicum*: A review. **Nauplius**, 17:61–79.
- Melo, G. A. S. 2003. Famílias Atyidae, Palaemonidae e Sergestidae. Pp. 289–415 In: Melo, G. A. S. (Ed.). **Manual de identificação dos Crustacea Decapoda de água doce do Brasil**. Editora Loyola, São Paulo, Brazil, 429 p.
- Paschoal, L. R. P., Guimarães, F. J. & Couto, E. C. G. 2013. Relative growth and sexual maturity of the freshwater shrimp *Palaemon pandaliformis* (Crustacea, Palaemonidae) in northeastern of Brazil (Canavieiras, Bahia). **Iheringia. Série Zoologia**, 103:31–36.
- Paschoal, L. R. P. & Zara, F. J. 2018. Sperm count of *Macrobrachium amazonicum* (Heller, 1862) populations with distinct life histories, with introduction of a simple counting method. **Aquaculture**, 491:368–374.
- Paschoal, L. R. P. & Zara, F. J. 2020. Size at onset of sexual maturity in *Macrobrachium amazonicum* (Heller, 1862) phenotypes: an integrative approach. **Anais da Academia Brasileira de Ciências**, 92:1–19.
- Primavera, J. H. & Qunitio, E. T. 2000. Runt-deformity syndrome in cultured giant tiger prawn *Penaeus monodon*. **Journal of Crustacean Biology**, 20:796–802.
- R Core Team. 2018. **R: A language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing.
- Ra'anan, Z., Sagi, A., Wax, Y., Karplus, I., Hulata, G. & Kuris, A. 1991. Growth, size rank, and maturation of the freshwater prawn, *Macrobrachium rosenbergii*: analysis of marked prawns in an experimental population. **The Biological Bulletin**, 181:379–386.
- Sampaio, C. M. S., Silva, R. R., Santos, J. A. & Sales, S. P. 2007. Reproductive cycle of *Macrobrachium amazonicum* females (Crustacea, Palaemonidae). **Brazilian Journal of Biology**, 67:551–559.

Received: May 2020
Accepted: October 2020
Published: March 2021