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INVASION OF THE THIARID SNAIL Melanoides tuberculata (MOLLUSCA) IN A CONSERVATION AREA OF THE SEMIARID REGION OF BRAZIL

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Abstract

This paper records the invasive gastropod *Melanoides tuberculata* in a limnetic ecosystem located in integral protection area in the semiarid region of the state of Paraíba in northeast Brazil. Live individuals were collected and photographed along shallow margins of the Piranhas Reservoir associated with different types of substrates. Photographic quadrants were used to calculate the number of living individuals and empty shells on different substrates. Individuals of *M. tuberculata* were found at five sampling sites in the littoral zone on different types of substrates with densities ranging of 13 ind.$(m^2)^{-1}$ to 22 ind.$(m^2)^{-1}$. The average density of individuals was: 18 ind.$(m^2)^{-1}$ on thin sediment, 15 ind.$(m^2)^{-1}$ on gravel and 20 ind.$(m^2)^{-1}$ on rocks. Empty shells were extremely abundant in the terrestrial zone of the reservoir. We did not observe native species of freshwater molluscs in the marginal areas of the reservoir in which the specimens of *Melanoides tuberculata* were found. Knowledge about the distribution, establishment and impact caused of *M. tuberculata* in limnetic ecosystems of the Brazilian semi-arid region needs to be better studied in order to ascertain the degree of impact on native species and environmental modifications that reflect negatively on ecosystems.

Keywords: Gastropoda. Thiaridae. Invasive species. Paraíba. Northeastern Brazil.

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1 Introduction

Freshwater biodiversity is under constant threat by numerous recurring impacts that amplify the negative effects on native species (DUDGEON et al., 2006; REID et al., 2019). Invasive species constitute one of these impacts that have led to the significant loss of biodiversity throughout the world (MCGEOCH et al., 2010; MOLLOT et al., 2017). A total of 163 non-native species are listed for freshwater ecosystems in Brazil, 40 of which are recognized as invasive (RESENDE et al., 2016). *Corbicula fluminalis* (Müller, 1774), *Corbicula fluminea* (Müller, 1774), *Corbicula largillierti* (Philippi, 1844), *Limnoperna fortunei* (Dunker, 1857), *Ferrissia californica* (Rowell, 1863), *Planorbella duryi (Wetherby, 1879)*, *Planorbella trivolvis* (Say, 1817), *Physella acuta* (Draparnaud, 1805), and *Melanoides tuberculata* (Müller, 1774) are among the invasive freshwater molluscs (FERNANDEZ et al., 2003; LEÃO et al., 2011; SANTOS et al., 2012; AZEVEDO et al., 2014, 2016; LACERDA et al., 2015), along with an unidentified morphospecies of *Corbicula* in the southern region of the country (SANTOS et al., 2012).

The species *M. tuberculata* (Mollusca, Gastropoda, Thiaridae) is a benthic snail from northeast Africa and southeast Asia (PILSBRY; BEQUAERT, 1927; SANTOS et al., 2016), but highly adapted for the invasion of wide variety of freshwater ecosystems around the world (BARROS et al., 2020), even in impacted environments (AZEVEDO et al., 2015). *M. tuberculata* is a parthenogenetic species and highly resistant to variations in environmental factors (e.g., salinity and temperature), which facilitates its dispersal and establishment in different habitats (DUGGAN, 2002; WEIR; SALICE, 2012; SANTOS et al., 2012; BARROSO et al., 2020). This thiarid snail can attain high population densities, exerting negative impacts on the structure of the ecosystem and native species (GIOVANELLI et al., 2005; LEÃO et al., 2011; LADD; ROGOWSKI, 2012; SANTOS et al., 2012, 2016; BRAGA et al., 2014; AZEVEDO et al., 2015; OLIVEIRA; OLIVEIRA, 2019). These attributes encouraged the introduction of this species for the biological control of vectors of schistosomiasis from the genus *Biomphalaria* (e.g., POINTIER et al., 1989, 1991, 1993), but the results were usually unsuccessful (COWIE, 2001). The aquarium trade can be considered an accidental source of introduction, as *M. tuberculata* is associated with plants sold at aquarium stores (VAZ et al., 1986; COWIE; ROBINSON, 2003; SANTOS et al., 2007; ASSIS et al., 2014). This snail also is the intermediate host of a number of trematodes of medical and veterinary importance, such as *Centrocestus formosanus* (Nishigori, 1924) and *Philophthalmus gralli* Mathis & Leger, 1910 (FERNANDEZ et al., 2003; KOCK; WOLMARANS, 2009; PINTO; MELO, 2010, 2012, 2013; LEÃO et al., 2011; SANTOS et al., 2012; POMBO, 2016).

M. tuberculata is widespread throughout the Neotropical region (FERNANDEZ et al., 2003; GIOVANELLI et al., 2005; COELHO et al., 2018; MIYAHIRA et al., 2020). Populations of this species have greatly expanded over the years in both lentic and lotic water bodies of South America, especially freshwater ecosystems in Brazil (LEÃO et al., 2011; LIMA et al., 2013; COELHO et al., 2018; MIYAHIRA et al., 2020), including environmental protection areas of the semiarid region (PAZ et al., 1995; FERNANDEZ et al., 2003; SANTOS; ESKINAZI-SANT'ANNA, 2010; SOUTO et al., 2011; LIMA et al., 2013; SILVA; GOMES, 2014; AZEVEDO et al., 2015; SANTOS et al., 2016; CHAGAS et al., 2018; ; OLIVEIRA; OLIVEIRA, 2019; SILVA et al., 2019; BARROS et al., 2020). Although several records of occurrence are found, there is a need for further research to quantify the invasion potential of this species. New records of invasive species are also useful for the development of conservation strategies for native species.

Among the environmental protection areas of Brazilian semiarid, Engenheiro Ávidos Ecological Park (EAEP) began to receive water from the transposition of the São Francisco River in January 2022 with the aim of supplying areas affected by drought. Thus, monitoring the population of *M. tuberculata* in this area is essential to the development of strategies for preventing its spread to the reservoirs that these waters reach. The aim of the present study was to estimate the population density of *M. tuberculata* in the reservoir of the EAEP, which is an environmental protection area in the semiarid region of the state of Paraíba in northeast Brazil.

2 Material and Methods

Study Area

The EAEP is an integral protection area of about 1.3 km^2 shared by the municipalities of Cajazeiras and São José de Piranhas in the semiarid region of the state of Paraíba in northeast Brazil (06°59'39.73" S, 38°27'14.47" W, Figure 1A-C) (BANDEIRA et al., 2019). The EAEP had aquatic and terrestrial ecosystems used for leisure, fishing and agriculture (FEITOSA et al., 2002; SOUTO et al., 2019a,b). Aquatic ecosystems of this protected area are represented by streams, marginal lagoons, and the Piranhas Reservoir resulting from the damming of the Piranhas River mainly for the human water supply of neighbouring municipalities (FEITOSA et al., 2002; BANDEIRA et al., 2019).

Methodological Approach

In November 2017, living individuals of *M. tuberculata* were collected manually along shallow margins of the Piranhas Reservoir (06°59'25.4" S, 38°27'20.1" W: Figure 1C) during the dry period (lower water level) over a four-week period.

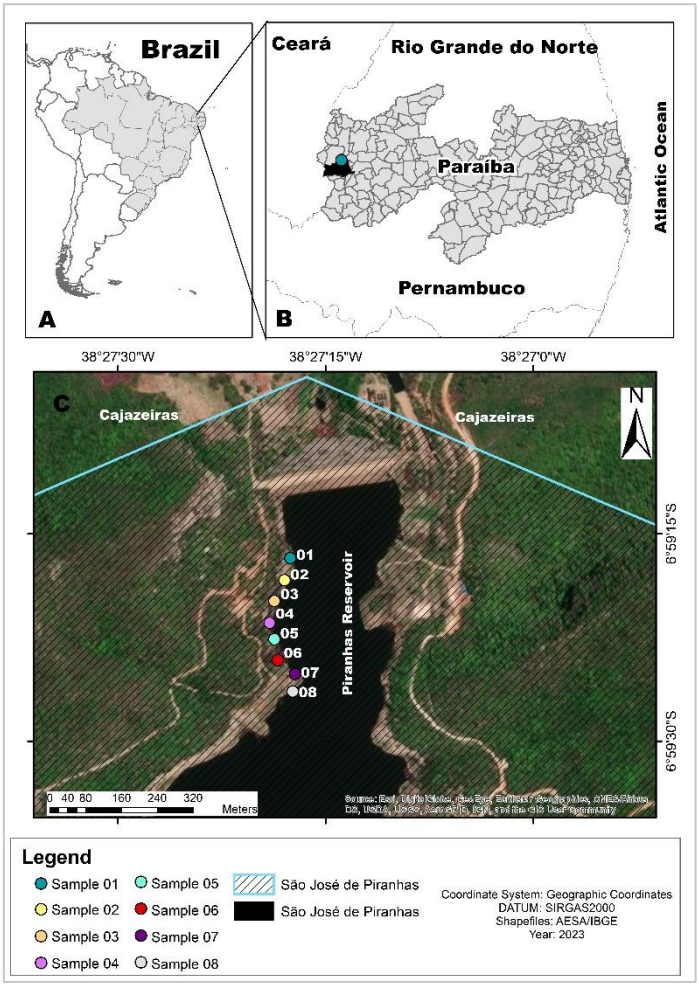

Figure 1. A: Map of Brazil highlighting State of Paraíba; B: State of Paraíba highlighting municipality of São José de Piranhas (black colour) and Piranhas Reservoir; C: Satellite photo showing Piranhas Reservoir and sampling points.

Living individuals were photographed at the margins of the reservoir (submerged or partially submerged) associated with thin sediment, gravel and rock aggregations at eight random sampling points per week [substrate terminology is based partly on Oliveira and Oliveira (2009) and Mansur et al. (2012)]. The number of empty shells was also determined on the exposed margin of the reservoir (terrestrial zone) due to the low water level. The individuals were photographed *in situ* with a digital camera and the images were used to calculate the abundance of living individuals on different types of substrate where the specimens were submerged or partially submerged at the study site. The abundance of empty shells on the exposed margin of the reservoir was also analysed for comparison (HUFF, 2011). A photographic quadrant measuring 50 cm^2 with four random replicates was established to standardize abundance within each replicate at 10 sampling points.

One-way analysis of variance (ANOVA) followed by Tukey's post hoc test was performed with the aid of GraphPad Prism 5.03 (significance level of $p < 0.05$) to determine differences in the number of individuals of *M. tuberculata* among studied sites.

3 Results

Living juveniles and adults of *M. tuberculata* were found at five of the eight sampling sites in the littoral zone of the Piranhas Reservoir, with densities ranging from a minimum of 13 ind.$(m^2)^{-1}$ to a maximum of 22 ind.$(m^2)^{-1}$ (Figures 2-3). This thiarid species was found on different types of substrates, always associated with slight microalgal biofilm. Some individuals were observed in deeper areas of the reservoir (< 1 m), but were not collected for the density assessment. The average density of individuals in the littoral zone associated with different types of substrate was 18 ind.$(m^2)^{-1}$ on thin sediment, 15 ind.$(m^2)^{-1}$ on gravel and 20 ind.$(m^2)^{-1}$ on rocks. The average density of empty shells in the terrestrial zone was 138 ind.$(m^2)^{-1}$, with maximum shell density of about 720 ind.$(m^2)^{-1}$ (Figure 2). We did not observe other freshwater molluscs in the marginal areas of the reservoir in which the specimens of *M. tuberculata* were found (Figure 3). Figure 3 shows empty shells in the terrestrial zone (Figure 3A), aggregation of living individuals partially submerged on rock aggregation in littoral zone (Figure 3B) and aggregation of living individuals submerged on gravel in littoral zone (Figure 3C).

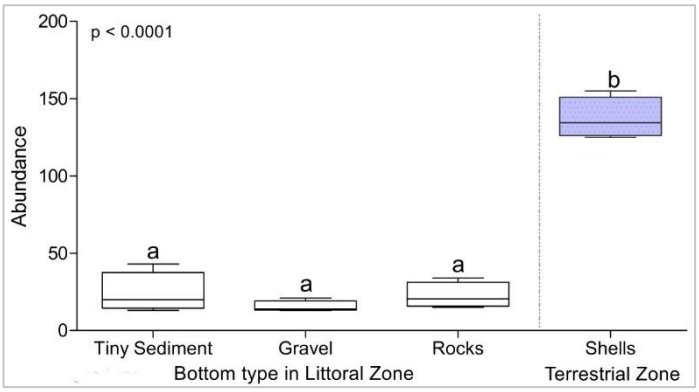

Figure 2. Average density of *Melanoides tuberculata* among substrate types in littoral zone and number of shells deposited in terrestrial zone (exposed margin) of Piranhas Reservoir (State of Paraíba, northeast Brazil). Boxplot graphs, including standard error bars, that indicate 95% confidence intervals.

4 Discussion

The invasive snail species *Melanoides tuberculata* has not previously been recorded for the municipalities of Cajazeiras and São José de Piranhas.

Nonetheless, it has already been recorded in other areas of the state of Paraíba – e.g., municipalities of João Pessoa, Campina Grande, Santa Luzia, São Mamede and Sousa (PAZ et al., 1995; COELHO et al., 2018). This new record likely indicates that the species is widespread in the state as well as the Piranhas River basin. The bioecology of *M. tuberculata* favours the rapid spread and establishment of individuals in lotic and lentic freshwater ecosystems with different environmental conditions (FERNANDEZ et al., 2003; GIOVANELLI et al., 2005; BARROS et al., 2020), especially in anthropized areas. Opportunistic species benefit from these modified environments and can establish their populations. The arrival of this thiarid occurred before the transposition of the São Francisco River to the region, which began in 2004 and was concluded in 2022. Although important for the water supply, the channels created provide a gateway between the São Francisco River and coastal rivers basins of northeast Brazil. Santos et al. (2022) recorded the golden mussel, *L. fortunei*, in these channels in the state of Alagoas. The channel that supplies the state of Alagoas is not the same that which conducts water to the state of Paraíba, but the population of the São Francisco River can be a source of propagules for all channels. Thus, the golden mussel could be an invader in the Piranhas Reservoir in upcoming years.

Figure 3. The snail species *Melanoides tuberculata* associated with different substrate types in the studied littoral zone and empty shells deposited/found in terrestrial zone: A. Empty shells in the terrestrial zone; B. Aggregation of living individuals partially submerged on rock aggregation in littoral zone; C. Aggregation of living individuals submerged on gravel in littoral zone.

The presence of *M. tuberculata* in the Piranhas River has likely had a set of negative impacts for native benthic species and the biotope. This invasive thiarid can reach high population densities in freshwater ecosystems (MANSUR et al., 2012; MMA, 2016; CHAGAS et al., 2018), affecting the structure of the native benthic community mainly due to competition for space and food sources (LADD; ROGOWSIK, 2012; MANSUR et al., 2012; BRAGA et al., 2014; MMA, 2016; PAULA et al., 2017; QUIRÓS-RODRÍGUEZ et al., 2018). Almeida et al. (2018) and Oliveira and Oliveira (2019) also recorded high densities of *M. tuberculata* in reservoirs located in the semiarid region of the state of Pernambuco (northeast Brazil).

In the Cachoeira II, Jazigo and Serrinha reservoirs, the density of this snail ranged from 62.08 ind.$(m^2)^{-1}$ to 1856 ind.$(m^2)^{-1}$ (ALMEIDA et al., 2018; OLIVEIRA; OLIVEIRA, 2019), which is higher than that reported in the present study. In contrast, Rocha-Miranda and Martins-Silva (2006) found sparsely distributed individuals of *M. tuberculata*, with a low average density [2 ind.$(m^2)^{-1}$] in the Paranã River Basin in the state of Goiás. Different densities may reflect the stage of introduction or a reaction to environmental conditions.

Miyahira et al. (2020) reported that *M. tuberculata* is the most widespread species in Brazilian reservoirs. This new record in the semiarid region of Paraíba adds one more record. The species has previously been recorded in reservoirs of the Parnaíba River basin (MIYAHIRA et al., 2020). Despite this, freshwater fauna, especially molluscs, is not well-known in northeastern Brazil.

The high concentration of empty shells accumulated in the terrestrial zone was the most visible impact affecting the area of the reservoir studied. Numerous empty shells of this species are often reported in freshwater ecosystems associated with different substrates (SANTOS; ESKINAZI-SANT'ANNA, 2010; SANTOS et al., 2012; ALMEIDA et al., 2018; OLIVEIRA; OLIVEIRA, 2019). A similar situation was also observed by Ilarri et al. (2020) for the Asian clam *Corbicula fluminea* (Müller, 1774) in a highly invaded area in the Minho estuary, Iberian Peninsula (ILARRI et al., 2020).

The large shell deposits were the result of the progressive deaths of individuals following the lowering of the water level. As the reservoir is used for leisure, the large quantity of dead shells can be a drawback to this use.

Moreover, the large quantity of shells and associated organic matter can lead to an increase in the eutrophication of reservoirs during the rise in water level, which can result in cyanobacterial blooms and fish mortality (MANSUR et al., 2012).

Several studies have also found this thiarid snail associated with macrophytes (MANSUR et al., 2012; MEDEIROS; HENRY-SILVA, 2017; OLIVEIRA; OLIVEIRA, 2019). However, the individuals studied here were found on the margins of the reservoir (water and air interface and below the water surface) with no aquatic plants, exposed to direct sunlight in an environment with clearly higher temperatures. In contrast, Rocha-Miranda and Martins-Silva (2006) found individuals of *M. tuberculata* only in shady areas in the Paranã River basin. This demonstrates that the invasive snail is a clearly generalist species with regards to habitat preferences, tolerating environments with differences in temperature and exposure to sunlight (DUGGAN, 2002; ROCHA-MIRANDA; MARTINS-SILVA, 2006; MMA, 2016).

The presence of this thiarid in a conservation area is worrisome, as its high invasiveness may exert negative impacts on the aquatic biota. Further studies should be conducted in this reservoir for a proper assessment of the impacts of *M. tuberculata*. As the reservoir has multiple uses, the presence of this snail can affect not only the native biota, but also the human population in different ways (economic, cultural and in terms of public health). Moreover, the connectivity with the water system associated with the project to transfer the waters of the São Francisco River can increase the dispersal of the species, as previously seen for fishes (RAMOS et al., 2021).

5 Conclusions

Knowledge about the distribution, establishment and impact caused by invasive molluscs such as *M. tuberculata* in limnetic ecosystems (including reservoirs) mainly in the semi-arid region of northeastern Brazil needs to be better studied. Long-term-research is essential in order to ascertain the degree of impact on native species and environmental modifications that reflect negatively on ecosystems.

In addition, its high presence may indicate the decline/disappearance of native freshwater species. Nonetheless, further studies are required to investigate the effects of this invasive species in dams for human supply and other limnetic environments.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Evandro Abreu and Silvio Lima conceived the research ideas and designed the study. Evandro Abreu, Silvio Lima, J. Weverton Souza and Jéssica Prata performed data analysis. Evandro Abreu, Silvio Lima, Jéssica Prata, Igor Miyahira, Marcelo Brito, J. Weverton Souza and João Silva wrote and approved the final manuscript.

DECLARATION OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence this paper.

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