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New bioinvasion in the Amazon: first record of the golden mussel *Limnoperna fortunei* (Dunker 1857) in the Tocantins River (Eastern Amazon)

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Abstract

Limnoperna fortunei (Dunker 1857) is a species of mytilid mollusk popularly known as the "golden mussel". Native to Southeast Asia, *L. fortunei* was introduced into Brazilian waters via ballast water in the 1990s and, due to its biological and ecological characteristics, found a favorable environment for its proliferation in the country. In the Brazilian scientific literature, records of *L. fortunei* are well documented, as well as the environmental and economic impacts caused by the species. In this context, we record the first occurrence of *L. fortunei* for the Brazilian Amazon region. The record occurred in August 2023 at seven collection points in the Tocantins River, with a maximum density found of 88.0 individuals/m^2, average anteroposterior length of 8.20±2.27 mm, ranging from 4.40 mm to 14.20 mm. The data presented in this study enables the mobilization of researchers and responsible bodies to create methodologies aimed at monitoring the species in the Tocantins River and adjacent rivers.

Key words: Amazon region, invasive species, bivalve mollusc, mussels.

Resumo - Nova bioinvasão na Amazônia: primeiro registro do mexilhão dourado *Limnoperna fortunei* (Dunker 1857) no rio Tocantins (Amazônia Oriental)

Limnoperna fortunei (Dunker 1857) é uma espécie de molusco mytilídeo conhecido popularmente "mexilhão-dourado". Nativo do sudeste asiático, a introdução de *L. fortunei* em águas brasileiras ocorreu via água de lastro na década de 1990 e, devido as características biológicas e ecológicas, encontrou no país um ambiente favorável à sua proliferação. Na literatura científica, os registros de *L. fortunei* são bem documentados, bem como os impactos ambientais e econômicos causados pela espécie. Neste contexto, registramos a primeira ocorrência de *L. fortunei* para a região amazônica brasileira. O registro ocorreu em agosto de 2023 em sete pontos de coleta no rio Tocantins, com densidade máxima encontrada de 88,0 indivíduos/m^2, comprimento anteroposterior médio de 8,20±2,27 mm, variando de 4,40 mm a 14,20 mm. Os dados apresentados neste estudo possibilitam a mobilização de pesquisadores e órgãos responsáveis a fim de criar metodologias objetivando um monitoramento da espécie no rio Tocantins e nas áreas adjacentes.

Palavras-chave: Região amazônica, espécie invasora, molusco bivalve, mexilhões.

Resumen - Nueva bioinvasión en la Amazonía: first record of the golden mussel *Limnoperna fortunei* (Dunker 1857) in the Tocantins River (Eastern Amazon)

Limnoperna fortunei (Dunker 1857) es una especie de molusco mitílido conocido popularmente como "mejillón dorado". Originaria del Sudeste Asiático, la introducción de *L. fortunei* en aguas brasileñas ocurrió a través del agua de lastre en la década de 1990 y, debido a sus características biológicas y ecológicas, encontró

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un ambiente favorable para su proliferación en el país. En la literatura científica brasileña, los registros de *L. fortunei* están bien documentados, así como los impactos ambientales y económicos causados por la especie. En este contexto, registramos la primera aparición de *L. fortunei* en la región amazónica brasileña. El registro ocurrió en agosto de 2023 en siete puntos de colecta del río Tocantins, con una densidad máxima encontrada de 88,0 individuos/m^2, longitud anteroposterior promedio de 8,20±2,27 mm, variando de 4,40 mm a 14,20 mm. Los datos presentados en este estudio permiten movilizar investigadores y órganos responsables para crear metodologías dirigidas al monitoreo de las especies en el río Tocantins y ríos adyacentes.

Palabras clave: Amazonia, especies invasoras, moluscos bivalvos, mejillones.

Introduction

Limnoperna fortunei (Dunker 1857) It is a species of mollusk belonging to the Mytilidae family, popularly known as the "golden mussel". Native to Southeast Asia, the introduction of L. fortunei into South America occurred through the estuary of the Rio de La Plata (Argentina) due to transoceanic ships that traded with Southeast Asia (Mansur, Richinitti, & Santos, 1999). Currently, *L. fortunei* is present in water bodies in Argentina, Bolivia, Brazil, Paraguay and Uruguay (Miyahira et al., 2024), in Brazilian waters, its first record occurred via ballast water in the 1990s (Mansur, Richinitti, & Santos, 1999). In this context, Lucía, Darrigran, and Gregoric (2022) mention that this species is one of the main invaders recorded in the South American region.

Due to its biological and ecological characteristics, it found a favorable environment for its proliferation in the country (Bertão et al., 2021; Mansur et al., 2003; Morton, 1977). These characteristics allow *L. fortunei* to grow on both natural and artificial substrates (e.g. pipes and reservoir installations, ports, bridges, vessels, etc.), which allows high densities of individuals (Mansur et al., 2012; Oliveira et al., 2006; Santos, Mansur, & Würdig, 2008).

In the scientific literature, records of *L. fortunei* are well documented, as well as the environmental and economic impacts caused by the species (Ávila-Simas et al., 2019; Ayroza et al., 2019; Miyahira et al., 2024; Paula et al., 2021; Rosa et al., 2023; Santos & Souza, 2022). Furthermore, several control measures were sufficient to prevent the spread of the golden mussel (Bertão et al., 2021; Santos & Souza, 2022) and new records are constantly reported (Miyahira et al., 2024). In this context, environmental agencies responsible for monitoring are constantly establishing control measures for this species, such as *Portaria Ibama nº 3.639/2018* which approved the "*Plano Nacional de Prevenção, Controle e Monitoramento do Mexilhão-dourado (Limnoperna fortunei) no Brasil"* (Ibama, 2020).

In this sense, it is understood that the bioinvasion of mollusks (bivalves and gastropods) in the Amazon region is a serious problem to be debated, mainly due to the numerous species already recorded for the region (Barros, Santos, & Chagas, 2022; Beasley, Tagliaro, & Figueiredo, 2003; Pimpão & Martins 2008; Poleze & Callil, 2015). Thus, the present study aims to record the first occurrence of the golden mussel *Limnoperna fortunei* in the Amazon region.

Material and Methods

The study area is located on the Tocantins River, which together with the Araguaia River forms the Tocantins Basin, which extends for 2,500 km and has a drainage area of 767,000 km^2. The Tocantins River has its source in the state of Goiás and flows into the Pará River (the estuary of the Amazon River), at a distance of 200 km from the Atlantic Ocean (Mérona, 1986/87).

The sampling points were delimited in the coastal region of the municipality of Marabá, state of Pará, where 18 collection points were established. In the present study, two sampling methodologies were applied to collect macrobenthos: qualitative and quantitative. In the qualitative sampling, a D-net (250 µm mesh size) was used in active collection, in environments with depths of up to 50 cm and with substrate formed by stone and/or gravel, leaf litter, twigs, etc. The samples were stored in plastic bottles (500 ml), labeled and fixed in 4% formaldehyde. In the quantitative sampling, a Van Venn grab (area 0.0682 m^2) was used, with only 1 replicate collected at each sampling station, both on the banks and in the middle of the Tocantins River. The quantitative samples collected were stored in plastic bags and fixed in 38% formaldehyde.

In the laboratory, the samples were washed in running water using sieves with a mesh size of 0.5 mm. After washing, the macrobenthos were separated by similarity of morphotypes and quantified. The taxonomy was confirmed after comparison with specific literature (Mansur & Pereira, 2006; Mansur et al., 2012; Pereira, Mansur, & Pimpão, 2012; Simone, 2006).

In order to obtain preliminary data on the golden mussel population, the population density – number of individuals collected per square meter (m^2) of sampled area – was determined based on quantitative sampling. In addition, biometric characterization was performed by measuring the anteroposterior length of the mussels, as Barros, Santos, and Chagas (2020), with the aid of a digital caliper (accuracy 0.01 mm). Subsequently, the mussels were grouped into length classes of 1 mm.

Results and discussion

In total, 32 individuals of *L. fortunei* (Figure 1) were found in August 2023, in the Tocantins River. After taxonomic confirmation from external and internal morphological characteristics of the shell, the individuals found were deposited in the Malacological Collection of the UFRA Zoology Museum (MUFRA) with vouchers MZUFRA 1374, MZUFRA 1399, MZUFRA 1410, MZUFRA 1418, MZUFRA 1425, MZUFRA 1431, MZUFRA 1444 and MZUFRA 1459.

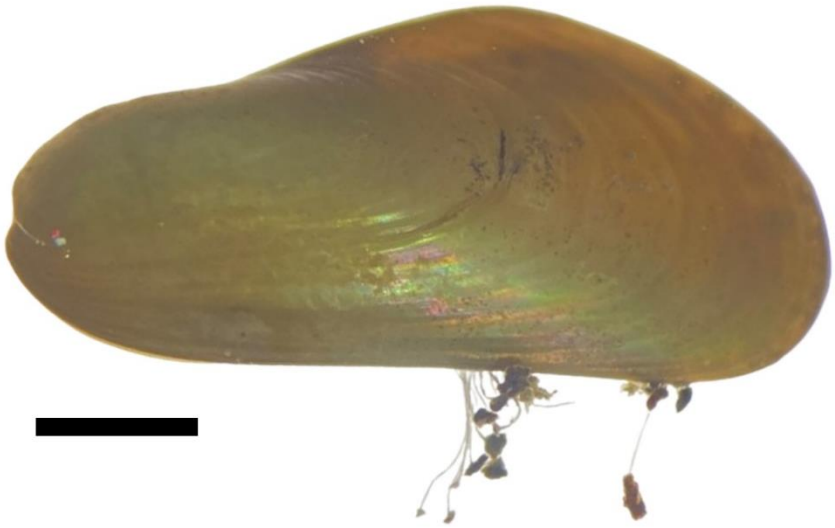

Figure 1. Specimen of golden mussel *Limnoperna fortunei* found in the Tocantins River. Scale: 1,0 mm.

In total, mussels were found at seven of the 18 collection points in the Tocantins River (Figure 2), with an average density ranging from 14.7 to 88.0 individuals/m^2. The maximum density found, as well as the largest individual recorded, suggests that colonization in the region is recent. This is an indication already reported by several authors, such as, Mansur et al. (2003) who recorded low densities initially (November 1999) in Lake Guaíba and Laguna dos Patos, Rio Grande do Sul, with an increase in the following months (27,275 individuals/m^2 in April 2000), reaching 100,000 individuals/m^2 in January 2001. In the Brazilian scientific literature, the highest reported density is 291,028 individuals/m^2 found in the pipes of the Xingó reservoir, in Alagoas, northeastern Brazil (Santos & Souza, 2022).

The mussels had an average anteroposterior length of 8.20±2.27 mm, with 4.40 mm and 14.20 mm being the smallest and largest individuals found, respectively. In total, the individuals belonged to 10 length classes, with the majority (84.3%, N=27 individuals) being between 5 and 10 mm in size (Figure 3). Studies on mussel growth are scarce, but Darrigran (2002) indicates that *L. fortunei* has great reproductive power and rapid growth, and can have three settlements throughout the year (Morton, 1977). In his study, Santos, Mansur, and Würdig (2008) found that *L. fortunei* grew an average of 11.63 mm (minimum of 4.40 mm and maximum of 29.97 mm) in one year, well below the 20 mm reported by Goto (2002) at Velvet Beach – Japan.

In the scientific literature, records of *L. fortunei* are well documented, with the last record of the species occurring in the Paraíba do Sul River, located in the state of Rio de Janeiro (Miyahira et al., 2024). In this study, the authors carried out an extensive bibliographic review of records of *L. fortunei* in Brazilian continental waters and showed that, to date, there were no records for the North region, nor for the Amazon region (Figure 2). Furthermore, Barbosa et al. (2018) carried out simulations for the years 2030-2050 and predicted a high risk of invasion in the north and northeast of Brazil. However, the present study confirms that the invasion occurred well before projected.

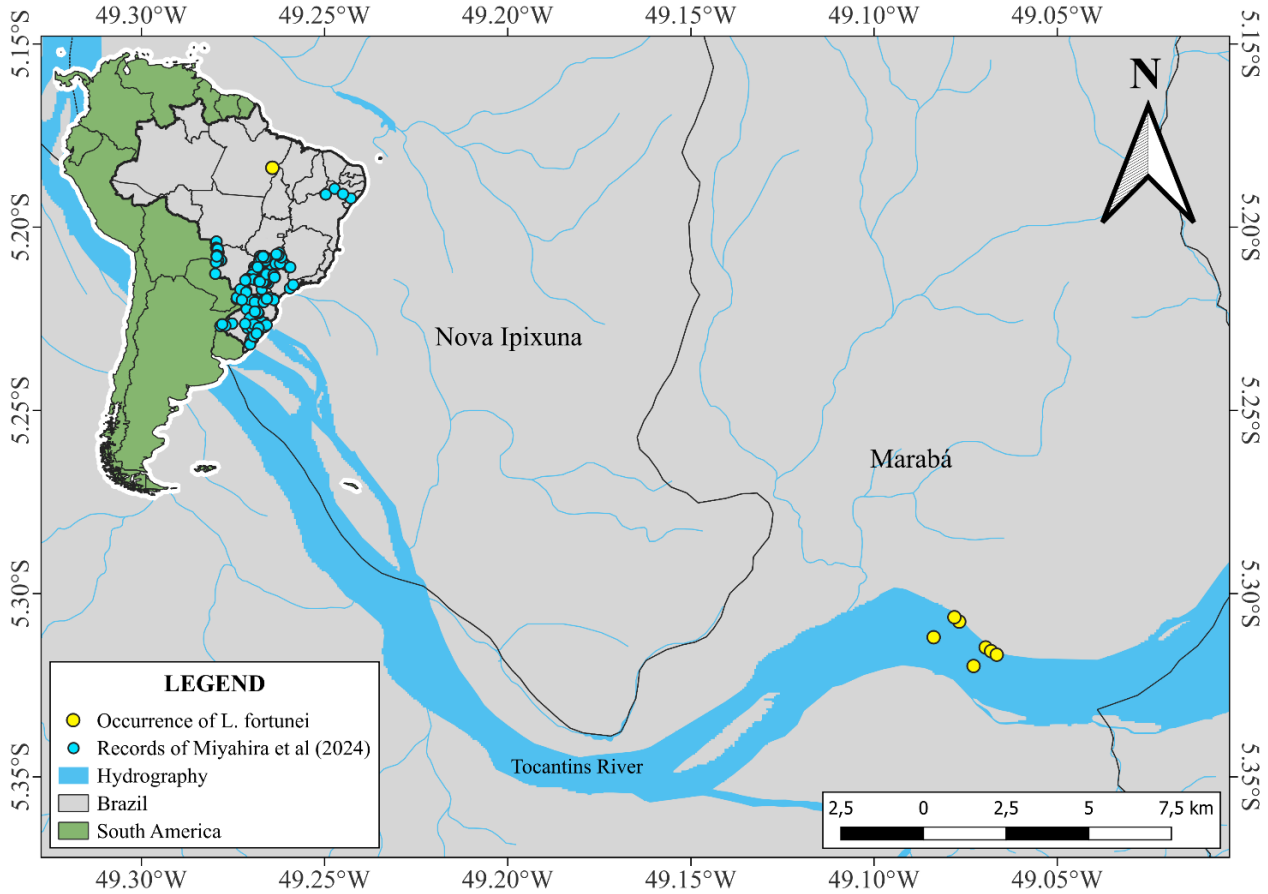

Figure 2. Location map of records of the golden mussel *Limnoperna fortunei* in the Tocantins River, State of Pará (Eastern Amazon) (●) and records in other Brazilian regions available at Miyahira et al. (2024) (●).

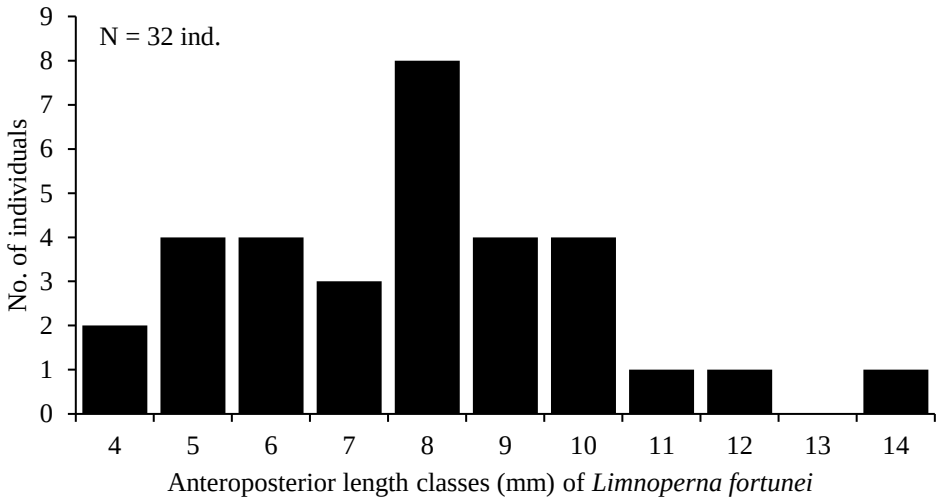

Figure 3. Anteroposterior length classes of golden mussel *Limnoperna fortunei* collected in the Tocantins River, Pará State (Eastern Amazon).

The environmental impacts caused by the presence or high density of mussels are numerous, such as on aquatic habitats, macrophytes and periphyton, planktonic organisms, benthic fauna, ichthyofauna, water quality and the trophic chain as a Whole (Ávila-Simas et al., 2019; Bertão et al., 2021; Miyahira et al., 2024; Oliveira et al., 2006; Santos & Souza, 2022). In addition, it causes economic impacts, including on energy generation and reservoirs, water collection and treatment, aquaculture and fishing, navigation and waterways, irrigation and tourism (Ayroza et al., 2019; Paula et al., 2021; Rosa et al., 2023; Santos & Souza, 2022). Several vectors associated with human activities (e.g., navigation, aquaculture, biological sampling, etc.) and natural vectors (e.g., migratory fish, connectivity between basins, macrophytes, birds, etc.) are related to the dispersal

of the golden mussel, but little is known about the effective contribution of each of them. Several prevention methodologies are known (Ibama, 2020; Santos & Souza, 2022), but there is no effective measure in the literature for eradicating this invasive species. The main control actions are those that involve monitoring the species from its first record in a given basin (Andrade, Razzolini, & Baggio, 2021; Ribolli et al., 2021). Therefore, mussel records are essential as they make it possible to predict and monitor new infestations, as well as assess the possible impacts generated by their infestation.

Conclusion

This study presents the first record of the golden mussel in the Amazon region. The record occurred in the Tocantins River, with densities of up to 88.0 individuals/m^2 and anteroposterior length of up to 14.20 mm. This record of the species in the region is extremely important and worrying, since projections estimated that the species would reach the Amazon region from 2030 onwards.

The data presented in this study will enable researchers and responsible agencies to mobilize in order to create methodologies aimed at monitoring the species in the Tocantins River. Furthermore, the experiences of monitoring measures with the same objective, as well as the results of studies carried out in other Brazilian regions, will assist in the development of preventive initiatives. In addition, we recommend that studies be carried out on the dispersal of larvae, ecology and population dynamics of the species, focusing on the environmental characteristics of Amazonian rivers, among others.

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