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Current distribution of the invasive mollusk *Corbicula fluminea* (O.F. Müller, 1774) (Bivalvia, Cyrenidae) in Brazil, including a new record from the state of Piauí

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Abstract

Corbicula fluminea is an invasive clam originally from Asia that threatens the biodiversity of freshwater communities around the world. It has greatly expanded in Brazil since its first record. We report here the occurrence of *C. fluminea* from Piauí state, Parnaíba river basin and, provide an assessment of its current distribution in Brazil. The compiled data include 382 records in 22 states and the Federal District, encompassing a variety of ecosystems. These results contribute to a discussion about the invasion and expansion process of *C. fluminea* in Brazil over time.

Keywords

Bioinvasion, freshwater bivalve, semi-arid region

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Introduction

Invasive species are characterized by their ability to cause ecological and economic impacts on ecosystems outside of their native range (Lockwood et al. 2007). Generally, such invaders exhibit opportunistic behavior, allocating a large amount of energy for reproduction (r-strategists), which can occur several times a year (Crespo et al. 2015). In addition to the inherent attributes of invasive species, successful invasions depend on the mechanism of introduction and features of the invaded environment (Sousa et al. 2008; Simberloff 2009; Crespo et al. 2015).

Biological invasions are among the main threats to the biodiversity of freshwater ecosystems, and some freshwa-

ter invasive mussels are among the most harmful organisms. This is especially true for *Corbicula fluminea* (O.F. Müller, 1774) (Sousa et al. 2008), a species originally from Southeast Asia and currently found on all continents (Poleze and Callil 2015; Gama et al. 2017). The first occurrence of *C. fluminea* in Brazil was recorded in the Rio Grande do Sul state in 1979 (Veitenheimer-Mendes 1981) and, since then, it has been recorded in all major hydrographic basins of the country (Santana et al. 2013). In the Northeast Region, it was recorded in the states of Bahia, Maranhão, Paraíba, Pernambuco, Rio Grande do Norte, and Sergipe (Santana et al. 2013; Almeida et al. 2015). Besides *C. fluminea*, three additional congeners have invaded Brazil: *C. fluminalis* (O.F. Müller, 1774), *C. largillierti* (Philippi, 1844), and *Corbicula* sp., and may have been misidentified as *C. fluminea*. Accounts on the identification and taxonomy can be found in Santos et al. (2012).

Corbicula fluminea presents high invasive potential and adaptive success in new environments due to rapid growth, early sexual maturation, short life cycle, high tolerance to different abiotic conditions, and dispersal ability. *Corbicula fluminea* is commonly dispersed through birds (but also through other animals), water streams, or by human action (such as ballast water, sand transportation, and fishkeeping) (Poleze and Callil 2015; Gama et al. 2016; Gomes et al. 2016). These features make *C. fluminea* one of the main agents responsible for economic losses in hydroelectric and water treatment plants. High population densities in these locations commonly cause duct clogging and increased corrosion rate in pipes (Ilarri and Sousa 2012; Gama et al. 2017).

Ecologically, the invasion by *C. fluminea* changes the structure and the function of ecosystems and biotic interactions by forming highly dense populations (Ilarri and Sousa 2012). Such changes are mainly caused by the mussel's high suspended solid filtration capacity, which influences light penetration and enacts subsequent changes in sediment composition, substrate-water column oxygenation dynamics, and nutrient cycling (Ilarri and Sousa 2012; Santana et al. 2013; Gomes et al. 2016). These environmental alterations affect the development of other organisms such as algae, freshwater sponges, crustaceans, insects, and gastropods (Sousa et al. 2008). *Corbicula fluminea* can affect native freshwater mussels through displacement or reduction of habitats available to juveniles. Competition for food, and ingestion of sperm, larvae (glochids), and juvenile individuals belonging to other mussel species are also relevant (Sousa et al. 2008; Ilarri and Sousa 2012; Modesto et al. 2019).

Considering the high invasive potential of *C. fluminea* and its consequent economic and ecological impacts, it is important to understand the patterns of dispersion in non-native areas, accessing its updated distribution. This can help in predicting potential sites for new invasions and supporting preventive and controlling strategies, as well as identifying the main routes of introduction (Karatayev et al. 2007; Ilarri and Sousa 2012; Silveira et al. 2016). The objective of this study is to gather information on the current distribution of this species in Brazil and to record the occurrence of the species in the state of Piauí. Consequently, new elements to understand the process of introduction over time and the expansion of this mollusk in the country are provided.

Methods

Specimens were collected monthly between June 2017 and September 2019 in the urban perimeter of the Itaim River, in the city of Itainópolis, in southeastern Piauí. The 200 km-long Itaim River belongs to the Parnaíba river basin and covers the municipalities of Paulistana, Patos do Piauí, Itainópolis, Santa Cruz do Piauí, Paquetá, and Oeiras. The collection area is located in the semi-arid region of the country characterized by low rainfall, high evaporation rates, and high temperatures throughout the year (Ab'Sáber 2003; Silva et al. 2020).

The five sampling stations were located on the urban stretch of the river. The sampling was conducted using a sieve (21cm diameter) attached to a 1.5 m-long wooden rod. The sieve was dipped five times into the bottom of the river to take the sediment, and the specimens were then removed from the sieve using forceps. The separation and identification were preliminarily carried out considering the external and internal morphology of the shell, following Simone (2006), Mansur (2012), and Almeida et al. (2015). The *C. fluminea* individuals were preserved in 98% ethanol. Specimen lots were sent to the Museu de Zoologia da Universidade de São Paulo, São Paulo, Brazil (MZUSP) to confirm the identification. Field samplings were authorized by the Chico Mendes Institute for Biodiversity Conservation (ICMBio), through the Biodiversity Authorization and Information System (SISBIO), permit number 60423-5.

Information on the current distribution of *C. fluminea* in Brazil was obtained through extensive bibliographic search using the keywords *Corbicula fluminea* and Brazil, in the Google Scholar databases, National Center for Biotechnology Information (NCBI), Online Scientific Electronic Library (Scielo), Springer, and Science Direct. We selected scientific articles, theses, dissertations, and scientific meeting proceedings. Documents that did not mention vouchers deposited in scientific collections and/or how the specimens were identified were excluded from the research. The search also gathered data from specimens deposited in the Mollusca collection of the Museu de Zoologia da Universidade de São Paulo (MZUSP). The geographic coordinates available in the research sources were used to create a distribution map. When not included in the publications, the center coordinates of the municipality were adopted as the geographic position. This method of reviewing the distribution of species based on published data and scientific collections has already been used to gather information on the distribution of other mollusk species (Coelho et al. 2018; Santana et al. 2013; Miyahira et al. 2020).

Four categories were established to determine the types of environments in which the species was recorded in Brazil:

i) natural lotic environments: brook, creek, stream, river, and waterfall
ii) natural lentic environments: lake and pond
iii) anthropized environments: mining pit, dam, and reservoir
iv) unusual environments: one in which the species is not usually found, such as beaches and shale pits

Some records in natural environments occurred within areas of environmental protection, classified at the federal, state, and municipal levels.

Results

***Corbicula fluminea* (O.F. Müller, 1774)**

New record. BRAZIL • 3 living specimens; state of Piauí, Itainópolis, Itaim River; 07°26.54′S, 041°28.35′W; July 2019, 18 cm depth, sandy substrate; August 2019, 14 cm depth, sandy substrate and September 2019, 16 cm depth, sandy substrate; 1 specimen MZUSP 151417; Leal, M.F. (Fig. 1).

In total, 382 records were obtained in the bibliographic survey, with greatest number of records in the Southeast Region (*n* = 242, 63.4%), followed by the South (*n* = 57, 14.9%), Midwest (*n* = 44, 11.5%), North (*n* = 22, 5.8%) and Northeast regions (*n* = 17, 4.5%). There are records for *C. fluminea* in 179 municipalities belonging to 22 Brazilian states in addition to the Federal District (Fig. 2). This species occurs in all states of the South, Southeast, and Midwest regions. In the North Region, it occurs in four of the seven states and in the Northeast Region, in six of the nine states. Our new record of *C. fluminea* from Piauí is the first from this state and the Parnaíba river basin. With the addition of the Parnaíba river basin, *C. fluminea* is now known from every single river basin in the Brazilian territory (Fig. 2).

The highest portion of records occurred in natural lotic environments (*n* = 298, 78%), of which eight (2%) were within an area under the influence of a hydroelectric plant, followed by lentic natural environments (n = 70, 18.3%) and anthropized environments (*n* = 13, 3.4%) (Fig. 3). There was a single record (0.3%) from a beach (Fig. 3), which we classified as an unusual environment, probably a result of transportation. The examined literature indicated that 11 (3%) of the 368 records of *C. fluminea* in natural environments occurred inside environmental protection areas (Fig. 3).

Two (0.5%) of the 382 records of the species in Brazil did not present any information about the year of occurrence. The vast majority of records date from 2000, with special attention to 2019, which accumulated about a quarter of the records (*n* = 80) (Fig. 4). Malacological studies (*n* = 306, 80.1%) concentrate on the highest number of occurrences of *C. fluminea*. However, this species was also reported indirectly by research focusing on ecotoxicology (*n* = 47, 12.3%), aquatic invertebrates in general (*n* = 17, 4.5%), and ichthyology (*n* = 12, 3.1%).

Identification. The collected specimens of *C. fluminea* (Fig. 1) correspond to the descriptions given by Mansur and Pereira (2006) and Simone (2006); the triangular shell presents concentric striations on the external surface, generally a bright, yellowish-brown periostracum, an elevated and inflated umbo, and no pallial sinus. Variations in the internal shell color can occur (Foster et al. 2020) and are associated with environmental conditions (Ituarte 1994; Mansur 2012) and genetic variation (Qiu et al. 2001).

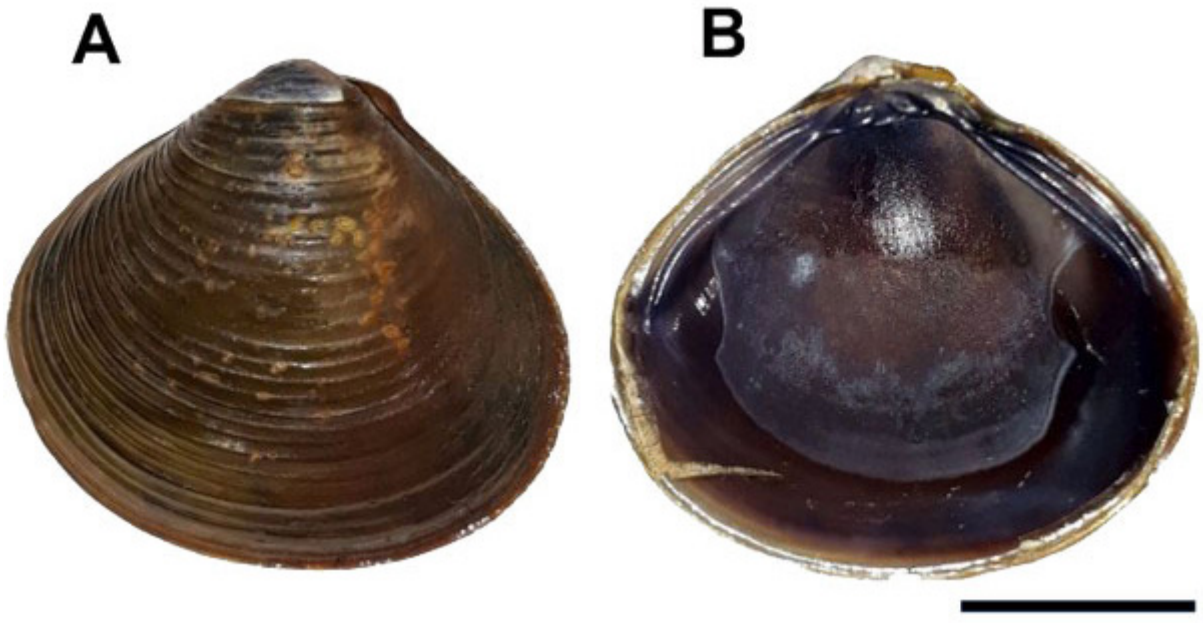

Figure 1. *Corbicula fluminea* specimen collected in the Itaim River, municipality of Itainópolis, Brazil. (MZUSP 151417, H 16 mm, L 19 mm). **A**. View of the outer surface, **B.** View of the inner surface. Scale bar = 10 mm.

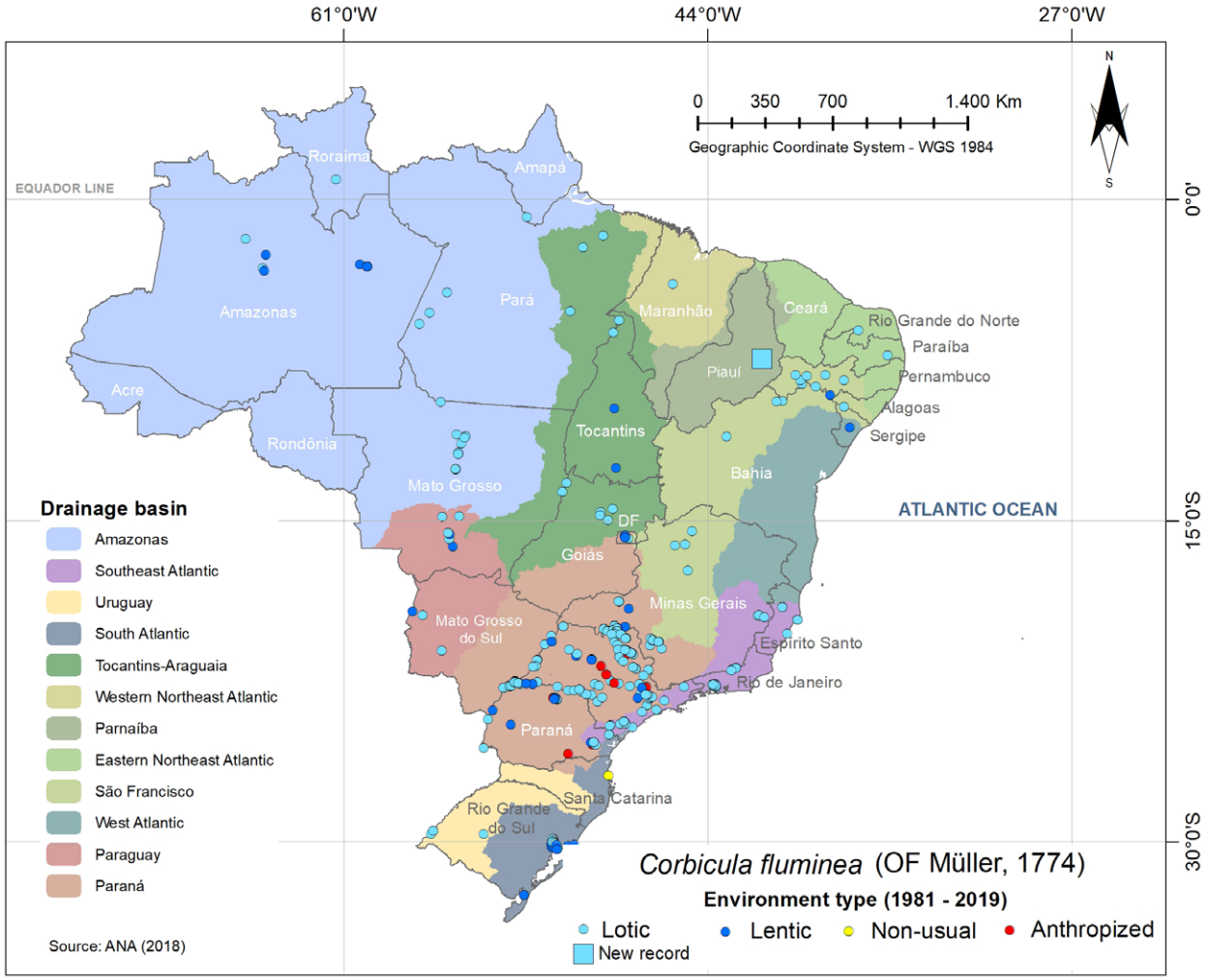

Figure 2. Geographic distribution of *Corbicula fluminea* in Brazil, including the new record for the state of Piauí.

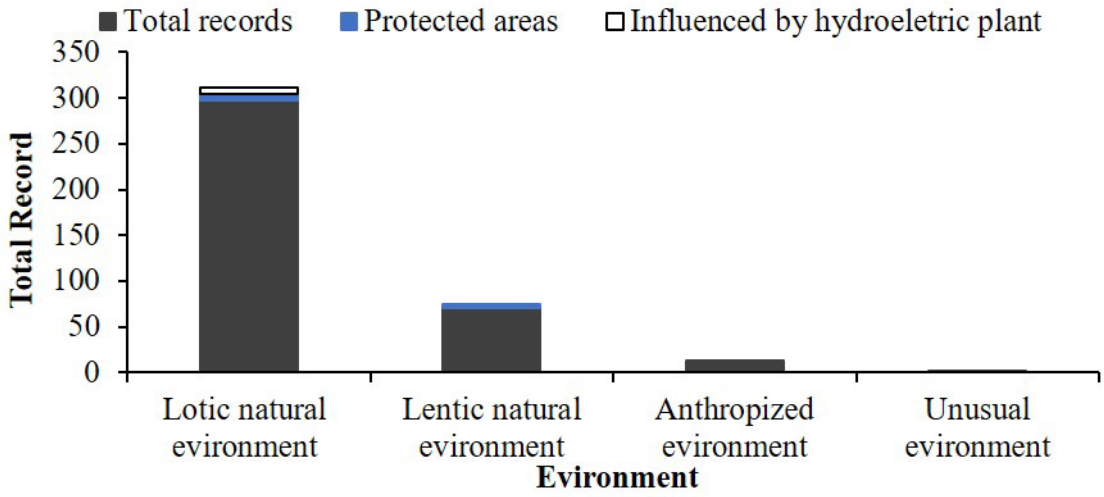

Figure 3. *Corbicula fluminea* records according to environment type in Brazil.

Discussion

The data presented in this work show that in the period of 40 years, *Corbicula fluminea* expanded its presence in the country, reaching 190 municipalities in all regions and all hydrographic basins, including the isolated Parnaíba river basin.

The high adaptive capacity of *C. fluminea* is proven by the diversity of environments in which it occurs (Sousa et al. 2008). High water temperature, shallow bed, and sandy substrate have been mentioned as ideal conditions to establish its populations (Zilli and Marchese 2011; Santana et al. 2013; Cao et al. 2017; Gama et al. 2017). These features are similar to the observed in the

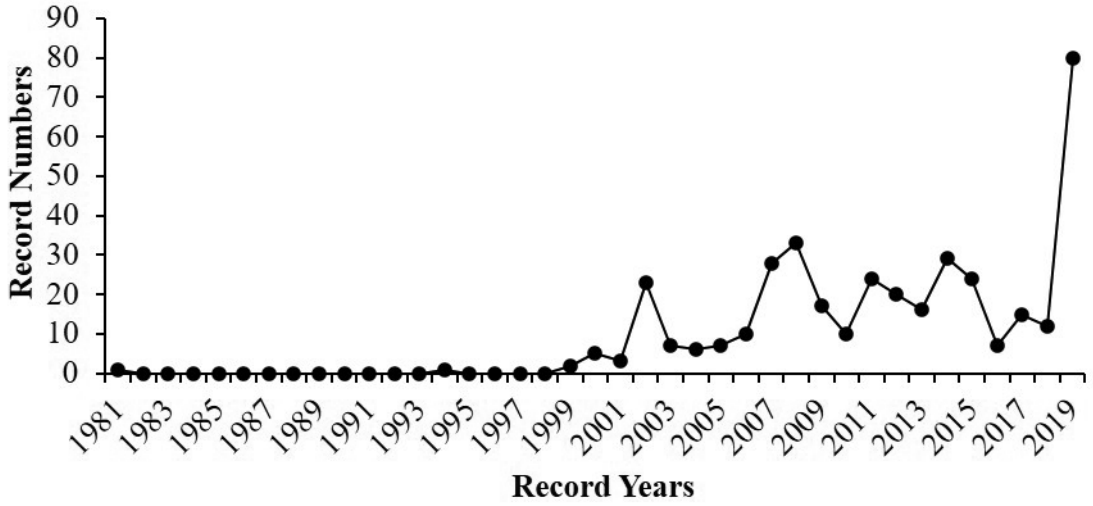

Figure 4. *Corbicula fluminea* recorded in Brazil, between 1981 and 2019.

Itaim River and most rivers of the semi-arid region. The occurrence of *C. fluminea* in this type of environment threatens native species and aquatic biodiversity, considering that most tributaries are intermittent, with frequent decreases their volume and flow of water. Thus, the semi-arid region is favorable to a population increase of this exotic species.

Records of *C. fluminea* in lotic, lentic, anthropogenic, and unusual environments demonstrate the high invasiveness of this mollusk and its risk to environments and biological communities within them. As verified in our research, the greatest number of occurrences are in lotic environments in Brazilian territory. This is expected and deserves attention as running waters have a greater capacity to easily disperse these bivalves to new areas (Poleze and Callil 2015; Rosa and Dantas 2020). Similarly, the greater occurrence number in natural environments, whether lotic and lentic, indicate significant stress on native fauna, considering environmental changes caused by high population densities of *C. fluminea*, as discussed by Sousa et al. (2008), Silva and Stuff (2011), and Sazima and D'Angelo (2013). Thus, actions to control and mitigate this bioinvasion in Brazil are urgently needed.

The economic impact of *C. fluminea* has been calculated for several regions of the country (Mota 2006; Paschoal et al. 2013; Paschoal et al. 2015; Paschoal et al. 2018; Maroneze et al. 2011), but the impacts on the Northeast Region have not yet been assessed. As the intermittent water bodies in this region have great importance in supplying cities and rural communities, as well as providing for livestock, irrigation, and leisure, the presence of *C. fluminea* in high densities might compromise water quality and its use. The transport of water for human use, which due to its scarcity is common in the semi-arid Northeast Region, may favor the dispersion of this and other exotic aquatic species between unconnected watersheds.

The main routes that have led to the rapid expansion of *C. fluminea* in Brazil are still not well documented because aquarium practices, transport by birds, sand extraction, and pisciculture may also have contributed to this process (Gomes et al. 2016; Belz et al. 2012). Regarding the pisciculture, Coelho et al. (2018) have already noted it as an efficient agent for dispersal. The compiled results of our study show a large increase in the number of records of *C. fluminea* from the 2000s onwards. These years coincide with the growth pisciculture activities in Brazil according to Schulter and Vieira Filho (2017). Also of importance, although species in the family Cyrenidae do not have fish-parasitizing larvae like the Unionoida, they still can use fish as a means of passive transportation for upstream dispersion in rivers. Therefore, it is common to find live specimens in the intestines of catfish (Loricariidae) (Simone personal observation), which evacuate them alive.

The continuous expansion of the distribution of *C. fluminea* in Brazilian water bodies, calls attention to the need for studies on population dynamics, modeling of habitat adequacy, as well as genetic variability of populations. These researches must be considered for the development of strategies to avoid the advance of new environments as well as to mitigate possible damages to the native fauna (Pigneur et al. 2013; Silveira et al. 2016; Fernandes et al. 2020).

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Authors contributions

MFL was responsible for the sample collection in the Itaim River, data analysis, and writing of the manuscript.

LRLS was responsible for the sample identification process and manuscript revision. ACFL coordinated data analysis and manuscript elaboration. ELS and TGP coordinated the research and revised the manuscript. All authors corrected, reviewed, and discussed the data.

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