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A New Record of a Nonnative Bivalve Species in an Amazonian Environmental Protection Area: What Might Have Happened?

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Abstract: *Corbicula fluminea* is an Asian mussel that has aggressively invaded freshwater habitats worldwide, causing damage both economically and with the disappearance of native species. In Brazil, this species is present in almost all watersheds, including areas of Federal Conservation Units. In this context, the present work reported the first record of *C. fluminea* in the Carajás mosaic, Pará, Brazil, a Federal Conservation Area. Collections were made in September and February 2021 and May 2022. In total, 154 specimens of *C. fluminea* were collected. The size range of the specimens was 16 to 28 mm in shell length and 1.46 to 5.91 g in wet weight. This new record extends the distribution of this species in South America and in the tropical watersheds of Brazil and is the first record in federal protected areas, highlighting the need for large-scale knowledge of the environmental and economic changes that the species can cause.

Keywords: invasive species; alien species; aquatic invaders; freshwater mussels; Brazilian Amazon; sustainability development objective of the United Nations (SDO#14)

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1. Introduction

Corbicula fluminea (O. F. Müller, 1774) (Bivalvia: Corbiculidae) is native to Southeast Asia, was introduced to North America in the late 19th century, and quickly spread throughout the Americas. It is edible, also known as Asian clam, and is now considered to be one of the species with the greatest invasive potential. *C. fluminea* is widespread in Brazilian freshwater basins, due to its aggressive behavior (high adaptability to environmental conditions) and capacity for environmental transformation (changes to the landscape). It was first recorded in Brazil by Veitenheimer-Mendes [1], and since then, it has dispersed to almost all regions. In southern Brazil, *C. fluminea* was described by Mansur and Garces [2]; in the southeast by Avelar [3], Suriani et al. [4], Vianna and Avelar [5], and Lima [6]; in the center-west by Callil and Mansur [7] and Poleze and Callil [8]; in the northeast by Santana et al. [9] and Rosa and Dantas [10]; and in the north, its occurrence was recorded by Beasley et al. [11] and Pimpão and Martins [12].

According to the Instituto Chico Mendes de Proteção à Biodiversidade (ICMBio) in Brazil [13], the control of biological invasion is among the main environmental challenges arising from anthropic impacts in Federal Conservation Units (UCs). In 2015, Guimarães [14] noted that of the 313 Brazilian UCs, *C. fluminea* was present in five of them. Recently, Leal et al. [15] gathered more than 100 occurrences of the species in aquatic environments, including urban environments and Protected Areas in Brazil. In the Carajás region (southeastern Pará state, Brazil), important mining and steel enterprises occur among a mosaic of conservation units, which include both areas of sustainable use and full protection. The mosaic is heterogeneous in terms of human use, including indigenous lands (Xikrin and Cateté) that coexist with legalized mining and with illegal gold miners [16].

Once established, *C. fluminea* can reduce the abundance of algae in large water bodies, negatively impacting fish species, crustaceans, and other components of the original

fauna [17]. Their high fecundity, ability to self-fertilize, fast growth, and early maturation (3 to 6 months), together with the high mobility of the pediveliger and juveniles facilitates a rapid dispersal from the original introduction site [18,19].

The filtration process generated by large colonies of *C. fluminea* increases water transparency, altering the production of algae and macrophytes, influencing the entire ecosystem dynamics [20–22], and causing modifications in the food chain [23,24]. Pigneur et al. [25] observed a 70% decrease in phytoplankton in the Meuse River in northwestern Europe due to the presence of *C. fluminea*. Takeda et al. [25] and Beasley et al. [11] observed a drastic decrease in populations of native benthic bivalve mollusks, mainly of the families Mycetopodidae and Hyriidae in the Paraná and Pará rivers, respectively, in Brazil.

Judging by the environment-modifying behavior already known in *C. fluminea* [17–19], this manuscript records the occurrence of the species in an environmental protection area, included in the region of the Carajás industrial complex (Carajás mineral province), with active mining of iron, gold, diamond, copper, manganese, and nickel [26]. This occurrence note opens discussions about potential dispersal agents of the species and highlights potentially effective measures to prevent further invasion and control the existing populations of *C. fluminea* in protected areas.

2. Material and Methods

2.1. Study Area

Sampling was carried out in the Igarapé Gelado Environmental Preservation Area (IGEPA) (Figure 1) (05°58.6′ S and 050°08.6′ W). The IGEPA is located close to Parauapebas city, southeastern Pará State, 645 km from Belém, Brazilian Amazon. It was created by Federal Decree No. 97,718 on 5 May 1989 and comprises an area of 21,600 hectares [27]. The Gelado creek has a sandy bottom with shells and rocks, pH of approximately 5.1, temperature of 26.5 °C throughout the year (in both wet and dry seasons), and a dissolved oxygen concentration up to 3 $mg.L^{-1}$ [26]. Igarapé Gelado is characterized by clear water according to Sioli [28], who classifies the Amazon waters as a typical 'Igarapé'.

The Gelado creek originates in the Serra dos Carajás and is a tributary of the Parauapebas River, widely used for recreation, fishing, and legal and illegal gold mining activities [26]. With an extension of about 60 km in the east–west direction and in the foothills of Serra dos Carajás, the IGEPA is bordered to the southeast by the Carajás Railroad, to the northeast by the Mombaca and Gelado creeks, to the northwest by the Azul and Itacaiúnas River, and to the south by the Carajás National Forest [16,26–28]. It is a sustainable use conservation unit formed by private and public areas Pontes and Bringel [29] and ICMBIO [27] with a hot and humid climate, type Aw according to Koppen's classification. Rainfall in the region ranges from 1700 to 2000 mm $year^{-1}$, with a more intense period between the months of November and April and a less rainy period comprising the months of May to October. The monthly temperature range varies between 25.1 and 26.3 °C with a relative humidity of approximately 70% in the driest months [16,26–31].

2.2. Biological Sampling

The specimens were collected manually with the aid of a dredge in September 2021 and February and May 2022. After collection, the individuals were placed in styrofoam with ice and taken to the Laboratory of Fisheries Biology of the Center for Aquatic Ecology and Fisheries of the Amazon at the Federal University of Pará, where they were identified, measured (cm), and weighed (in g). All the methods used in this study were authorized by means of a license from the competent environmental agency (SISBIO n°75796-4).

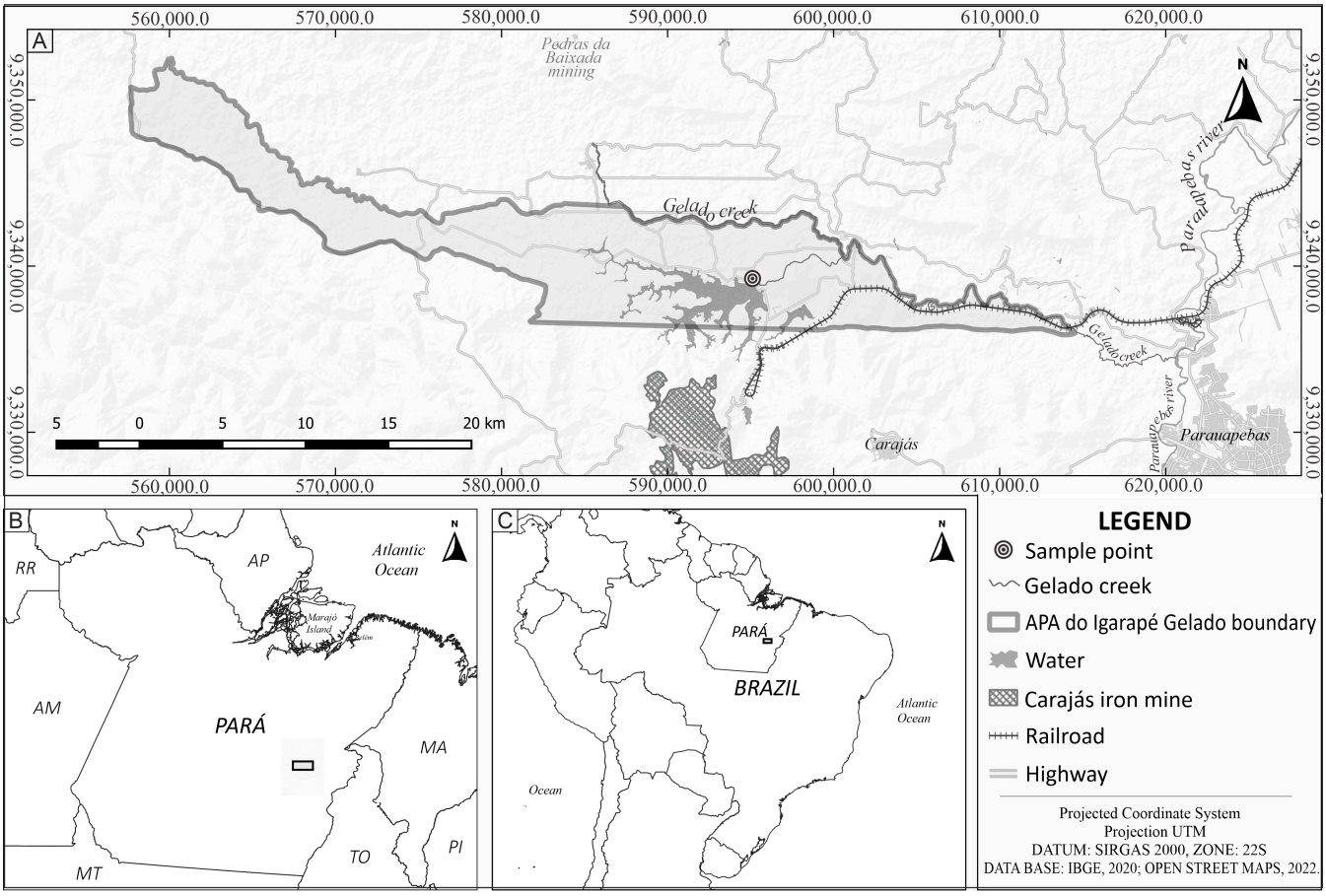

Figure 1. Location of the sampling point where the *Corbicula fluminea* specimens were collected in IGEPA Igarapé Gelado—Carajás Mineral Province, Brazil, in September 2021, February 2022, and May 2022. (**A**)—Protected area of Igarapé Gelado creek; (**B**)—Para state; (**C**)—Brazil.

3. Results and Discussion

A total of 154 specimens of *C. fluminea* were collected, 19 in September 2021, 34 in February, and 101 in May 2022 (Figure 2). The size range of the specimens was 2.8 to 1.6 cm in shell length and 5.91 to 1.46 g in wet weight Figure 3).

In the IGEPA, even though there are no active mines, it receives tributaries from the mines that cut through the creek of the same name. In addition, two mining tailings dams are located inside it. These dams are used for the conditioning of waste originating from the iron and manganese extraction process [16,29–33]. Data on the relationship between the construction of dams, especially within conservation units, and the presence of *C. fluminea* have not yet been reported in the literature, reinforcing the need for further studies, since there is modification in the environment that may propitiate the emergence of exotic species or provide opportunities for this to occur.

According to Leal et al. [15], the main routes that led to the rapid expansion of *C. fluminea* in Brazil are not yet well documented; however, in the case of the IGEPA, it is believed that the process of ship fouling may have been one of the vectors for the dispersion of this species, because the southeastern part of it is bordered by the Carajás Railroad, which connects the Carajás Mining Complex to the Ponta da Madeira Maritime Terminal in São Luís/MA. Its main function is ore transportation, but it also carries passengers between Parauapebas (Pará) and São Luís (Maranhão). In addition, one of the important hydrographic characteristics of the IGEPA is the existence of hydraulic structures in the form of dams on the Gelado and Geladinho creeks [31].

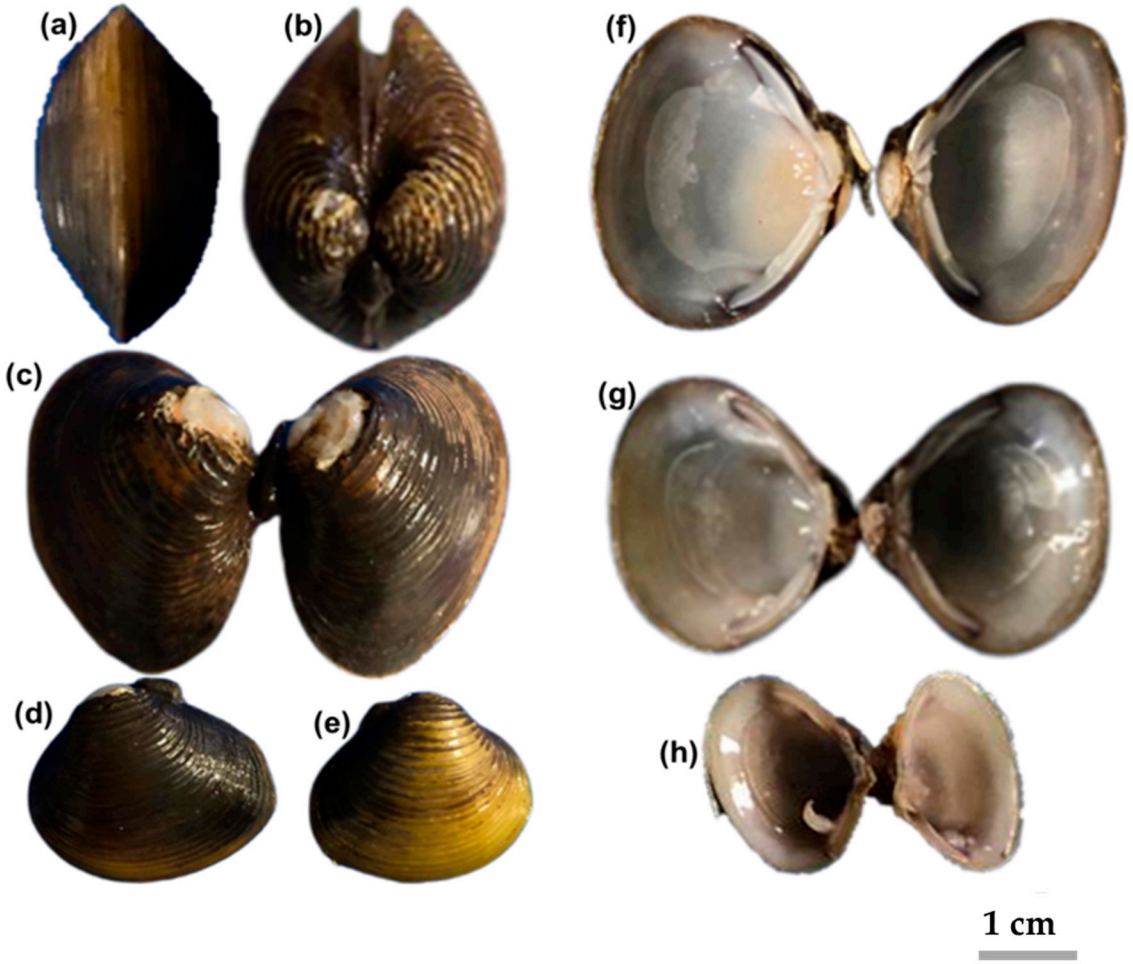

Figure 2. Samples of the *Corbicula fluminea* catch from September 2021, February 2022, and May 2022 found in the IGEPA Igarapé Gelado—in the province mineral of Carajás, Brazil; (**a**) external view of a closed specimen; (**b**) external view of a closed specimen; (**c**–**e**) external view of opened specimens in different sizes; (**f**–**h**) internal view of opened specimens in different sizes.

In general, the main vector of dispersion of this species in most of the sites recorded is ballast water, both from vessels that circulate the high seas and from cabotage ships that ballast and de-ballast in small ports along the Brazilian coast. The vessels that transport containers between countries can bring a lot of specimens through the bioencrustation process, but even though these vessels do not arrive in the IGEPA, the specimens of *C. fluminea* can easily access these ecosystems. In addition, if we consider continental waterways, both adult individuals and post-larvae can be transported inside cisterns or in the sand for construction and removal from contaminated water sources to other areas [16,27–34], which may have contributed to the invasion of this species in IGEPA. In studies conducted by Leal et al. [15] in watersheds in Brazil, occurrence records were found in 22 states and the Federal District (Figure 4).

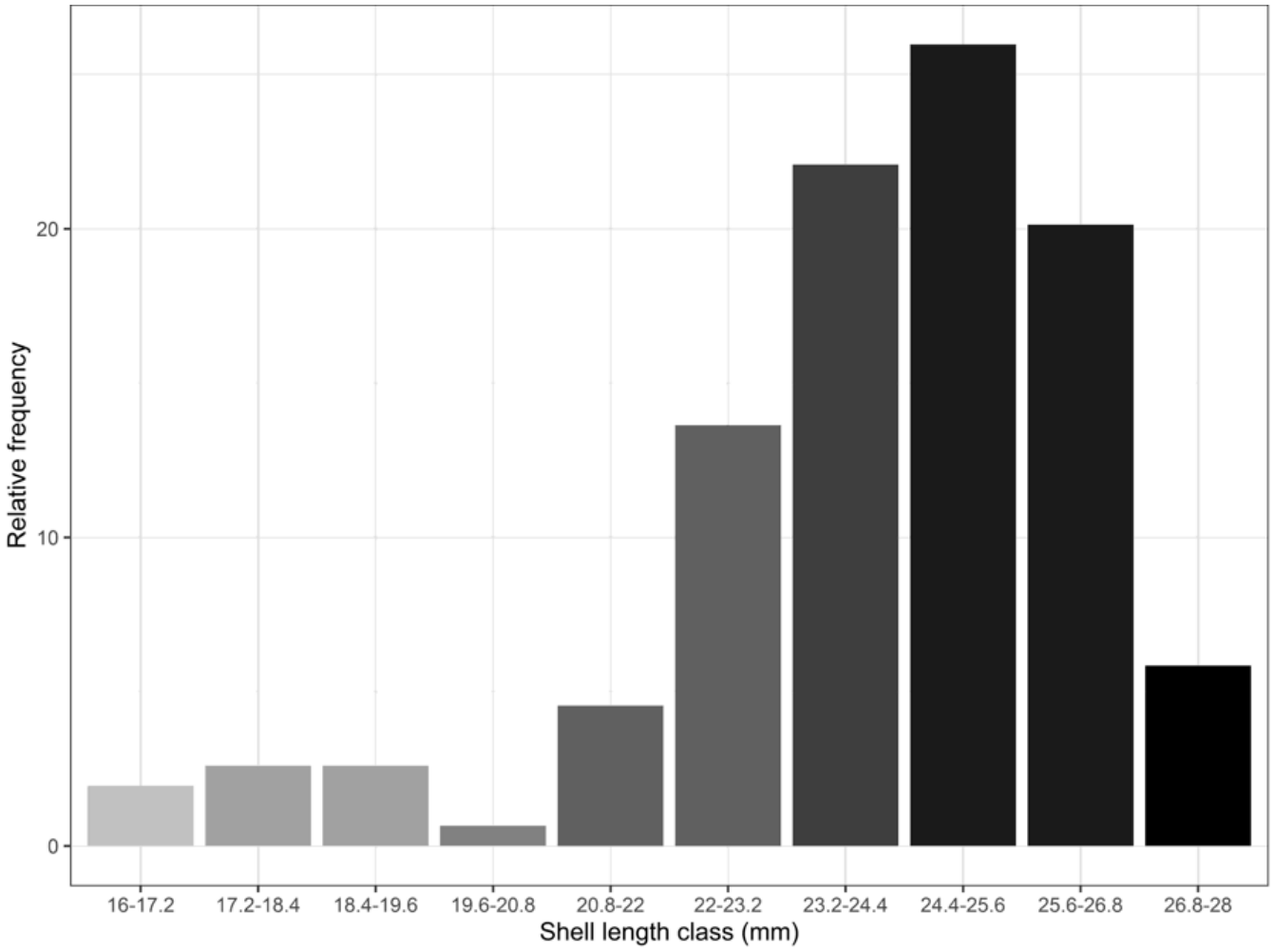

Figure 3. The relative frequency distribution of the length (mm) of *C. fluminea* found in IGEPA Igarapé Gelado, Carajás, Pará, Brazil, in September 2021, February 2022, and May 2022.

Furthermore, these authors observed that the species inhabits both lotic and lentic water environments, and most records found were for lotic environments. The IGEPA represents a lotic watercourse, since the water flow is controlled by a mining company. Sazima and D'Angelo [35] and Leal et al. [15] point out that, ecologically, the invasion by *C. fluminea* changes the structure and the function of ecosystems and biotic interactions by forming very dense populations and compromising the trophic chain, causing environmental stress.

In addition, according to Haubrock et al. [36], the cumulative global costs for *C. fluminea* control and mitigation between the years 1980 and 2020 in freshwater environments, were about USD 12.4 billion. Due to their small size and lightness in the larval (pediveliger) and juvenile stage, the individuals are sucked into the plumbing systems and pass through the protective filters. The mucus secreted during the juvenile phase, along with the growth of the specimens, generates major problems for industrial facilities, such as clogging pipes, which prevents the passage of water for urban supply, and the overheating of hydroelectric power plant systems [37–40].

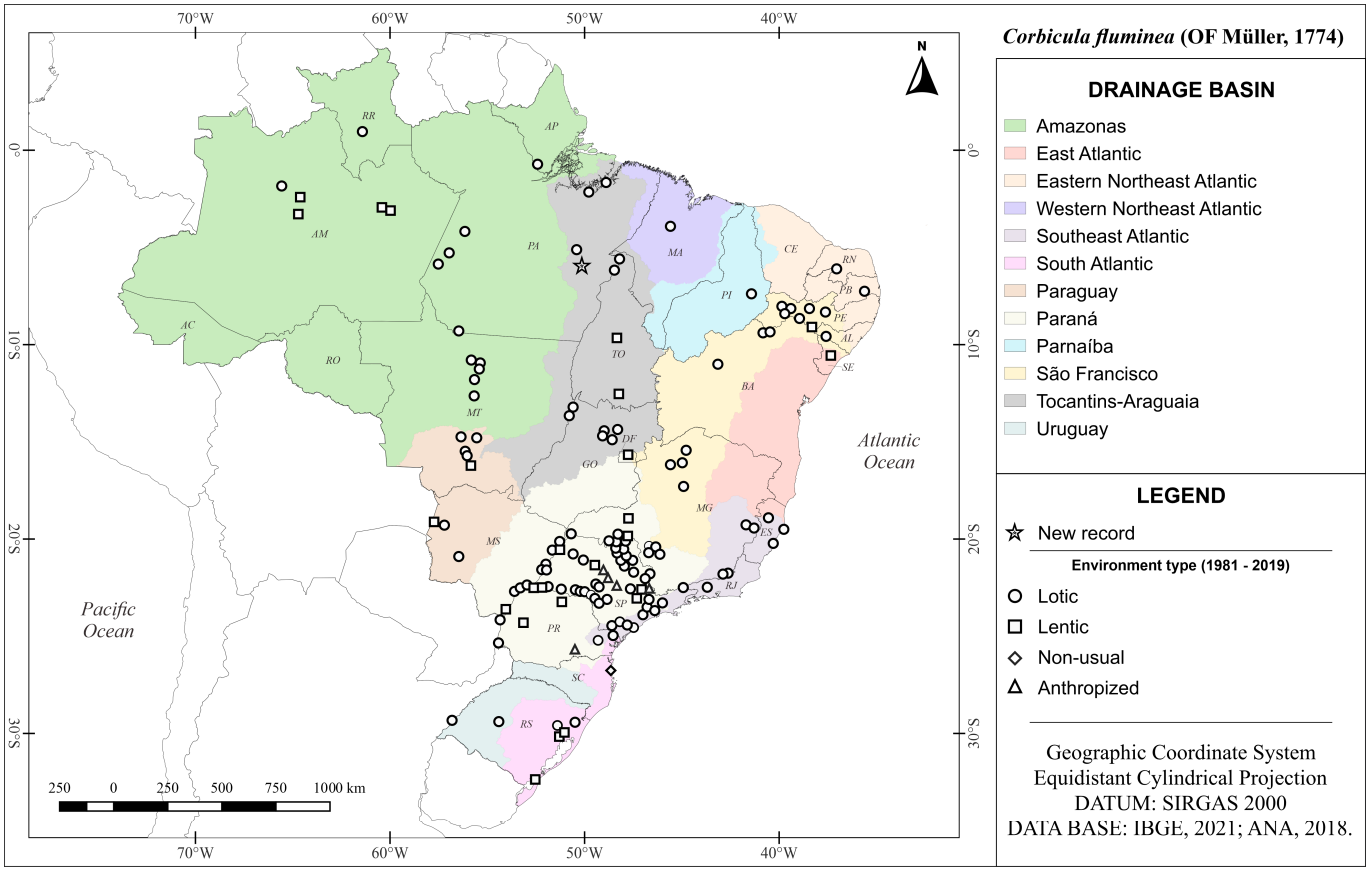

Figure 4. Distribution of *C. fluminea* in Brazil, including the new record for the APA do Igarapé Gelado Carajás Mineral Province, Brazil (Adapted from Leal et al. 2021) [15].

The control of this species has been debated for a long time by means of different methods [41–44]. The management strategy for these bivalves that presents the least cost to industrial facilities is prevention. However, when this species is not detected early, and infestation of industrial facilities by a population of *C. fluminea* occurs, or when the first infestation outbreaks are detected, control strategies are applied by chemical (by substances lethal to organisms), nonchemical (mechanical removal), and biological methods (introduction of predators such as carnivorous fish, preferably native species of the region) [42,43].

One of the paths of the dispersal of *C. fluminea* in the Carajás mosaic comes from the modifying of trophic links, which is evident when the bird species *Tachybaptus dominicus* (Linnaeus, 1766), locally called grebe or "mergulhão", actively feeds on the invasive species and thus configures itself as another dispersing agent of the species. In the scientific literature, there are already reports of the incidental transport of small juveniles attached to the legs or feathers of birds or transported inside the gastrointestinal tracts of fish or birds [44–46]. The mechanisms that facilitate the adaptive success of *C. fluminea*, in addition to what was mentioned above, are based on the high level of the hardiness of the species [47,48], translated into progressive (fast and efficient growth and reproductive cycle) and deleterious effects (negative effect on native species' densities) in various environments [49,50].

4. Conclusions

The present record of *C. fluminea* in the IGEPA extends the distribution of this species in the tropical watersheds of Brazil and South America, and it is the first record of this species in a Federal Protected Area, highlighting the need for large-scale knowledge of the environmental changes that the species can cause, especially in conservation units.

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