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Marine bioinvasions: bivalve molluscs introduced in northeast Brazil

Bioinvasões marinhas: moluscos bivalves introduzidos no nordeste do Brasil

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ABSTRACT: Invasive alien species are those that, once introduced from other environments, adapt, starting to reproduce and proliferate in places they did not previously inhabit. The introduction of exotic marine species as a result of anthropic activity, whether intentionally or not, is a process that has been remote for centuries, which makes it difficult to assess the impact of these activities, making studies that address the status of knowledge about such organisms always important. Thus, this research aims to gather information about bivalve molluscs introduced into marine ecosystems in northeastern Brazil, in addition to discussing the knowledge of this invasive fauna for the Northeast, Southeast and South regions of Brazil. For that there was a search for bibliography in 5 databases - SciELO, Web of Science, Google Scholar, ScienceResearch.com and I3N Brazil Database of the Horus Institute for Environmental Conservation and Development. Three invasive bivalves for the northeastern region of Brazil were counted. When compared to the South and Southeast regions, the Northeast presents a significant amount of research on the ecology of the species *Isognomon bicolor* (C. B. Adams, 1845) and *Mytilopsis leucophaeata* (Conrad, 1831), which is very important, because with these results it is possible to track and understand the pathways that make bioinvasions possible. Regarding *Perna Perna* (Linnaeus, 1758), although there is a discussion about its supposed introduction in Brazilian waters, the species can be considered invasive in Northeastern Brazil.
KEYWORDS: Invasive species, marine ecosystem, ecology.

RESUMO: As espécies exóticas invasoras são aquelas que, uma vez introduzidas a partir de outros ambientes, adaptam-se, passando a se reproduzir e proliferar em locais que outrora não habitavam. A introdução de espécies exóticas marinhas como resultado da atividade antrópica, seja de maneira intencional ou não, é um processo que remota há séculos, o que torna difícil avaliar o impacto dessas atividades, sendo sempre importante estudos que abordem o status de conhecimento sobre tais organismos. Dessa forma, essa pesquisa tem como objetivo reunir as informações sobre os moluscos bivalves invasores de ecossistemas marinhos do nordeste brasileiro, além de discutir sobre os conhecimentos dessa fauna invasora para as regiões nordeste, sudeste e sul do Brasil. Para isso, houve buscas pela bibliografia em 5 bases de dados - SciELO, Web of Science, Google Acadêmico, ScienceResearch.com e Portal I3N Brasil do Instituto Hórus de Conservação Ambiental. Foram contabilizados três bivalves invasores para a região Nordeste do Brasil. Quando comparado com as regiões sul e sudeste, o Nordeste apresenta uma quantidade significativa de pesquisas sobre a ecologia das espécies *Isognomon bicolor* (C. B. Adams, 1845) e *Mytilopsis leucophaeata* (Conrad, 1831), o que é muito importante, visto que, com esses resultados torna-se possível o rastreamento e compreensão das vias que viabilizam as bioinvasões. Em relação a *Perna perna* (Linnaeus, 1758), embora haja uma discussão sobre sua suposta introdução em águas brasileiras, a espécie pode ser considerada invasora no nordeste brasileiro.
PALAVRAS-CHAVE: Espécies invasoras, ecossistema marinho, ecologia.

INTRODUCTION

Species can be classified into three generic categories: exotic, native and cryptogenic (LOPES; VILLAC, 2009). Species classified as exotic can be included in four specific categories: contained, detected in a natural environment, established and invasive, assuming an increasing gradient of invasion potential. Native or wild species are those native to a given ecosystem or region. Finally, cryptogenic species are those of unknown or uncertain biogeographic origin (LATINI et al., 2016).

Invasive alien species are those that, once introduced from other environments, adapt, starting to reproduce and proliferate in places they did not previously inhabit. They are characterized by having fast maturation, great reproductive capacity and a tendency for populations to persist after colonizing these new environments (LATINI et al., 2016; DARRIGRAN; DRAGO, 2000).

The introduction of species in a new location can occur intentionally or unintentionally and is most often the result of anthropic activities that overcome natural barriers which, normally, prevented the entry of these new species in environments previously not accessible by natural paths (HEWITT; CAMPBELL, 2007). In Brazil, currently, the national database of invasive alien species of the Hórus Institute registers on its platform a total of 468 invasive species (INSTITUTO HÓRUS, 2020).

The establishment of these species in environments that are not of their origin can cause loss of local biodiversity, with major negative impacts, being able to change properties or processes at the ecosystem level, when the invaders differ from the natives in the acquisition or use of resources, modifying the trophic structure of the area (VITOUSEK, 1990).

Marine and freshwater ecosystems are particularly vulnerable to bioinvasions (SALA et al., 2000). Minchin et al. (2009) provide a comprehensive review of the vectors that contribute to the invasion of aquatic exotic species and point out eight main paths for a non-native organism to reach a new location. Among these vectors, navigation and cultivation of non-native species have been considered the most critical pathways for marine invasions worldwide (MOLNAR et al., 2008).

In the northeast of Brazil, some of the most serious cases of biological invasion in aquatic ecosystems are the consequences of voluntary introductions. Two emblematic cases are the tucunaré *Cichla ocellaris* and the tilapia *Oreochromis niloticus* in rivers, lakes

and dams, which certainly resulted in several local species extinctions, especially, with loss of biodiversity on a regional scale (ROSA; GROTH, 2004).

In the marine-coastal environment of the northeast, the following cases of biological invasions can be cited: the anemones *Diadumene lineata* and *Exaiptasia pallida*, and ascidian *Styela plicata* (FARRAPEIRA et al., 2007), crustaceans *Penaeus vannamei* (SANTOS; COELHO, 2002; TAVARES; MENDONÇA Jr., 2004), *Penaeus monodon* (COELHO et al., 2001; SANTOS; COELHO, 2002), *Temora turbinate* (CAVALCANTI et al., 2008; SILVA et al ., 2004), *Pseudodiaptomus trihamatus* (INSTITUTO HÓRUS, 2020), *Amphibalanus reticulatus*, *Amphibalanus subalbidus*, *Conchoderma auritum* (NEVES; ROCHA, 2008; FARRAPEIRA et al., 2007), *Conchoderma virgatum* (FARRAPEIRA et al., 2007, FOSTER; WILLAN, 1979), *Striatobalanus amaryllis* (FARRAPEIRA, 2008; FARRAPEIRA et al., 2007; NEVES et al., 2005) and *Charybdis hellerii* (COELHO; SANTOS, 2003), the jellyfish *Blackfordia virginica* (FREIRE et al., 2008; FREIRE; PÉREZ, 2007), and the polychaete *Polydora nuchalis* (INSTITUTO HÓRUS, 2020).

Among the main species introduced in the different ecosystems, those belonging to the phylum Mollusca stand out (CARLTON; GELLER, 1993; CARLTON, 1992). In aquatic environments, bivalve mollusks represent a threat to native species, due to their successful colonization (invasion) of an environment, as it has short longevity, rapid growth, phenotypic plasticity, dominance in its natural habitat and wide environmental tolerance, being able to colonize several types of habitats because they have great flexibility of physiological adaptations (BARBOSA, 2009).

Although marine bioinvasion is a recurring problem in Brazilian waters, it is noticeable that society has only recently begun to understand and study its ecological impacts (examples, XAVIER, 2008; MACHADO; PAIXÃO; OLIVEIRA, 2019; SILVA et al., 2018; SOUZA; CALAZANS; SILVA, 2009; TEIXEIRA et al., 2010; ZANELLA, 2015). Researches aiming at summarizing the invasive fauna are of great importance, since through this information it will be possible, later, to study their impacts of biological, economic and social nature. Therefore, this review aims to: (i) Gather information about bivalve molluscs introduced into the marine ecosystems of northeastern Brazil; (ii) Discuss the knowledge of this invasive fauna for the Northeast, Southeast and South regions of Brazil.

METHODOLOGICAL PROCEDURE

The search for the bibliography took place between the months of May and August 2020, and was carried out in five databases - SciELO, Web of Science, Google Scholar, ScienceResearch.com and I3N Brazil Database of the Horus Institute for Environmental Conservation and Development. The search on the I3N Brazil Database was carried out by taxonomy, choosing the following options: Kingdom (Animalia), Phylum (Mollusca), Class (Bivalvia). When searches on each database were completed, duplicate references were subsequently excluded. In the search, articles written in English and Portuguese were selected.

There are some problems and differences in the indexing processes in the bibliographic databases; thus, it was decided to search for free terms, without the use of controlled vocabulary, that is, descriptors. Using this strategy, a greater number of references was recovered, guaranteeing the detection of most of the published works within the pre-established criteria.

Regarding the inclusion and exclusion criteria, master's dissertations and doctoral theses, books, conference proceedings and original indexed articles were included, with research on taxonomy, reproduction, biological form, dispersion and its vectors, diet and preferred environments for invasion. Articles related to the cultivation of bivalves for economic purposes were excluded, as they did not directly assist in achieving the objective of this article.

MARINE BIVALVES INTRODUCED IN THE NORTHEAST

A review study carried out by Freire and Marafon (2018) brought together all species of molluscs introduced into Brazilian aquatic ecosystems, listing 8 species of bivalves, which are: *Corbicula fluminea* (O. F. Müller, 1774), *Isognomon bicolor* (C. B. Adams, 1845), *Limnoperna fortunei* (Dunker, 1857), *Perna perna* (Linnaeus, 1758), *Leiosolenus aristatus* (Dillwyn, 1817), *Corbicula largillierti* (Philippi, 1844), *Corbicula fluminalis* (O. F. Müller, 1774) e *Mytilopsis leucophaeata* (Conrad, 1831).

Species	Lifestyle	In the Northeast (States)	References
***Isognomon bicolor* (C. B. Adams, 1845)**	Epifaunal, it uses the byssus to attach in rocks, corals, calcareous algae and mangrove roots	Fortaleza Pernambuco Rio Grande do Norte Bahia Alagoas	Bezerra (2010) Farrapeira et al. (2007) Domaneschi and Martins (2002) Gomes and Silva (2013) Dias et al. (2013) Rios (2009)
***Perna perna* (Linnaeus, 1758)**	Epifaunal, it uses the byssus to attach in rocky shores	Rio Grande do Norte	Rios (1994) Freitas and Velastin (2010) Silveira et al. (2006)
***Mytilopsis leucophaeta* (Conrad, 1831)**	Epifaunal, it uses the byssus to attach on hard substratum	Pernambuco	Pathy and Mackie (1993) Galeão and Souza (2015) Maciel and Souza (2010) Nery et al. (2008) Souza et al. (2005)

Freire and Marafon (2018), however, did not include *Crassostrea gigas* (Thunberg, 1793), recorded by Melo et al. (2010) as an invasive species in natural oyster banks in Southern Brazil. In addition, the Asian mussel *Perna viridis* (Linnaeus, 1758) was recorded for the first time in the port area of Guanabara Bay, Rio de Janeiro (MESSANO et al., 2019) and Belz et al. (2020) registered the Mediterranean mussel *Mytilus galloprovincialis* Lamarck, 1819 as an invasive species on the Brazilian coast, in Florianópolis and Palhoça, state of Santa Catarina. Along the southeast and south coasts of Brazil *Saccostrea cucullate* (Born, 1778) is recorded (AMARAL et al., 2020). Thus, there are a total of 12 invasive bivalves for Brazilian aquatic ecosystems. Table 1 shows

the species of bivalve molluscs introduced into marine ecosystems, showing their habit of life and the states of the Federation in which they occur. Table 1: Invasive bivalves of marine ecosystems in northeastern Brazil.

In the south and southeast of Brazil, *I. bicolor* has already been registered for the states of Rio de Janeiro, São Paulo, Paraná, Santa Catarina and Espírito Santo, presenting a wide distribution (DOMANESCHI; MARTINS, 2002; FREIRE; MARAFON, 2018; ZAMPROGNO; FERNANDES; FERNANDES, 2010). *P. perna* occurs in São Paulo, Rio de Janeiro, Rio Grande do Sul, Santa Catarina and Paraná (HENRIQUES; CASARINI, 2009; PEREIRA et al., 2007, SOUZA et al., 2004). As for *M. leucophaeta*, with the exception of the northeast, there are records of occurrence only for the state of Rio de Janeiro (FERNANDES et al., 2020; RIZZO et al., 2014). Figure 1 shows the distribution of these 3 species in northeastern Brazil from data obtained in secondary databases.

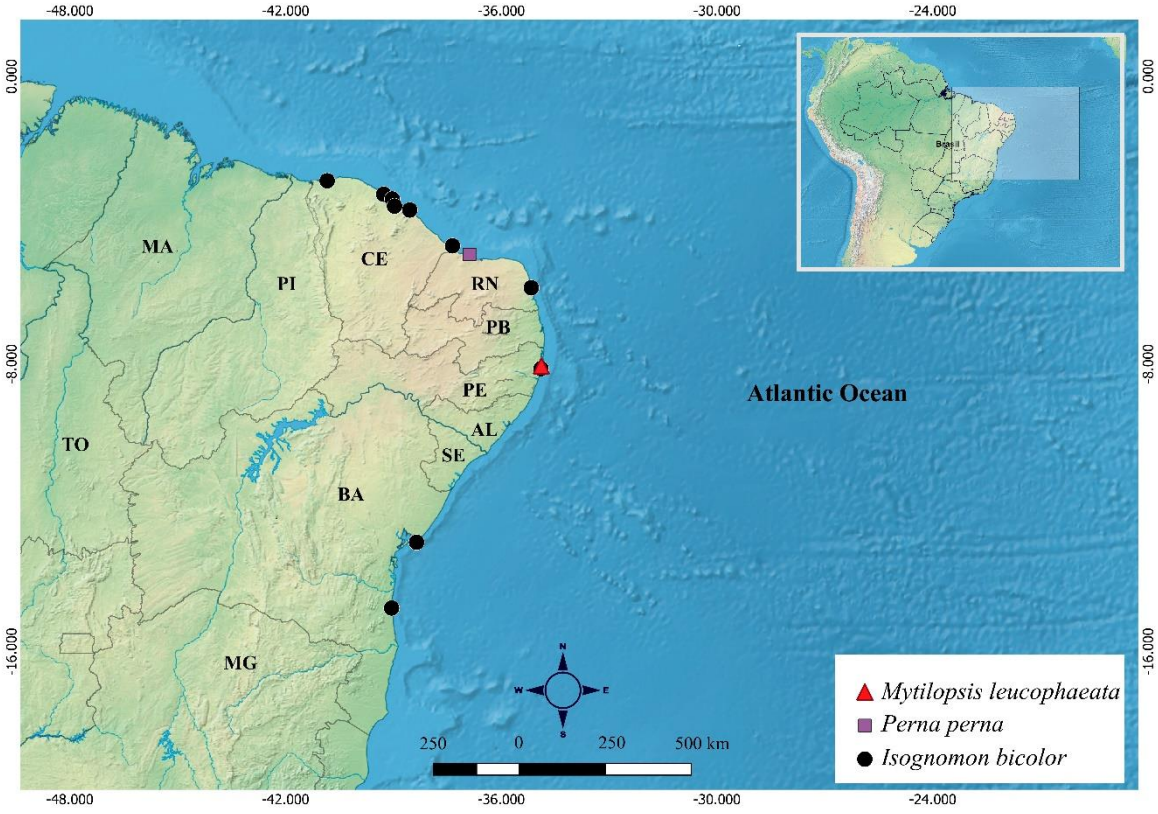

Figure 1: Distribution map of the species *I. bicolor*, *P. Perna* and *M. leucophaeta* in Northeast Brazil

In comparison to the number of records of occurrence of *P. Perna* that exist in the states of south and southeast northeast, there is a great inferiority in relation to the

states of the northeast, which may be related, using the argument of Haddad and Nogueira Júnior (2006), to the fact that the main ports in Brazil are located in the south and southeast regions, and by the presence of a greater number of researchers working in large research centers in São Paulo, Rio de Janeiro and Paraná.

Isognomon bicolor (C.B. Adams) (Isognomonidae)

According to Breves-Ramos et al. (2010), there are two possible vectors that made the unintentional introduction of bivalve *I. bicolor* feasible. The first would be the oil platforms that are brought into Brazilian waters from different regions, and the second would be the ballast water from ships. In addition to these two, Oliveira and Creed (2008) also point to gas platforms as a possible vector.

This bivalve can be found in hard substratum and its presence has been observed in tide pools up to the shallow infralittoral. On rocky shores with high wave energy, it can be found occupying crevices and in less hit places. Its distribution in broad densities, forming clearly differentiated occupation ranges, it has already been observed by Domaneschi and Martins (2002).

Regarding its population structure, a survey conducted by Bezerra (2010), in Ceará, shows that this species has a high density, limiting the ability that many native species could have to obtain food, in addition to preventing its fixation. This result was also obtained in surveys carried out on the coast of Rio de Janeiro (DOMANESCHI; MARTINS, 2002; FERNANDES et al., 2004; BREVES-RAMOS et al., 2010) and São Paulo (HENRIQUES; CASARINI, 2009). In addition, studies have assessed its spatial distribution on rocky beaches in the Southeast (ZAMPROGNO et al., 2010) and South (MARTINEZ, 2012) regions of Brazil. Given that *I. bicolor* has a wide distribution along the northeast coast, more research on its population structure, as well as spatial distribution, should be developed in the different states, in order to measure the probable damages that, perhaps, may be caused in the structure of the native communities.

Regarding evolutionary genetic studies, there is only research on the genetic variation of the species for the Southeast region (ARANHA, 2010; LOPES et al., 2017) and there are no studies with species that occupy the aquatic ecosystems of the Northeast. Understanding the biological processes related to invasions and their

evolutionary processes are very important to understand the potential for adaptation of a species.

Because the boinvasions cause significant changes in the abundance and distribution of species in receiving communities (RICCIARDI; MACISAAC, 2011), studies on its impacts become unique. In the Southeast, for example, López et al. (2014) evaluated the potential impact of the invasion of *I. bicolor* through research comparing before and after the arrival of this non-native species. Other experimental studies in the same region have reported their biological interactions with some native species, such as the positive association with the macro algae *Sargassum sp.* (LÓPEZ; COUTINHO, 2010) and the intensity of predation and the preference of native predators for *P. perna* and *I. bicolor* (LÓPEZ et al., 2010). In the Northeast, Queiroz (2015) characterized the structure of the macrobenthic community on beaches with the presence of the bivalve *I. bicolor* and evaluated whether their presence may be influencing or being influenced by the distribution and density of native species. According to the author, as most of the research on *I. bicolor* is carried out in the south and southeast regions, in some cases the researchers point out only the structural characteristics of the beaches and rocky shores as an important factor in the establishment of the species, however, the beaches and coastal areas in the northeast have different physiognomies, among many other distinct characteristics of the beaches in the South and Southeast, making it important to assess the conditions to which this bivalve is exposed in the Northeast.

Perna perna (Linnaeus, 1758) (Mytilidae)

There is a discussion about whether *P. Perna* is an invasive species in Brazil. Souza et al. (2003, 2004, 2005) after comparing the richness of the bivalve Pinctada imbricata in the sambaquis and in rocky shores of the south and southeast regions, found that this species was abundant in the sambaquis and rare in the nearby rocky shores. Such an event could indicate that this bivalve was seen in greater numbers in prehistoric times than in current times. Regarding *P. Perna*, its presence has not been confirmed for any sambaqui, however, currently, its presence is abundant in rocky shores. Thus, the authors suggested that *P. imbricata* was a food resource well used by prehistoric populations, being replaced, later, by the arrival of *P. Perna*, brought from

South Africa. Its possible bioinvasion on the Brazilian coast was also studied from a genetic point of view, showing a high genetic identity with populations in Africa (MOURA-NETO, 2003; WEBER; SILVA, 2008). This factor would be consistent with a model of continent-islands (WRIGHT, 1978) in which, possibly, one population, from Africa, served as the founder of several other populations, in this case, Brazilians.

Silva et al. (2018) studied the content of the sambaquis found in the entire distribution range of *P. Perna* along the Brazilian coast (578 sites), and dated some shells of this species. The results of these studies describe the same scenario proposed by Souza et al. (2003, 2004, 2005), that is, evidence that supports the hypothesis of its bioinvasion.

In contrast, Pierri et al. (2016) after studying the native or exotic condition of this mussel in Brazil, based on the survey of results in archaeological sites, molecular techniques and dating of shells with C14, they found that the calculation of the divergence time indicated that the separation of the Brazilian and African populations occurred around 200 thousand years ago. Thus, *P. perna* would be a native species. Still, for the author, all research does not lead to a conclusion, since they need specific studies, endowed with clear methodologies, combining archeology, ecology and molecular biology.

After studying the effect of ballast water discharged by merchant ships from Arraial do Cabo, Rio de Janeiro, Silveira (2005) recorded, for the first time, the presence of *P. perna* in Areia Branca, in the state of Rio Grande do Norte, probably introduced by ballast water. Thus, in any case, *P. Perna* is considered invasive in northeastern Brazil, because it is a species typical of the south and southeast regions (JHERING, 1900, SOUZA et al. 2004).

The species was registered in low densities in Areia Branca (RN), with young individuals that do not have well-developed populations. Its presence in this region is strong evidence of the transport of organisms from the southeast to the northeast of Brazil. Furthermore, this mussel is a typical organism that can be embedded in vessels, having probably been introduced in the Northeast via ballast water by vessels from the southeast of Brazil (SILVEIRA, 2005).

Regarding its ecological relations, in the southern region, a study by Freitas and Velastin (2010) on the ichthyofauna associated with a cultivation of *P. perna* in the north of Santa Catarina, showed that this bivalve has great relevance in the places they

inhabit, structuring communities on rocky coastlines, in addition to being a diversity bioatractor.

To the northeast, there is still no research on the ecology, interactions or possible impacts that the mussel *P. Perna* can cause on native fauna. The absence of studies may be due to the fact that it was registered only in Rio Grande do Norte and in low densities. Thus, it is suggested that more research be done in regions where ballast water is discharged by ships, in order to verify whether this species occurs in other states in the northeast region.

***Mytilopsis leucophaeata* (Conrad, 1831) (Dreissenidae)**

The first record of the occurrence of *M. leucophaeta* in Recife, Pernambuco, indicates the need for studies to determine the impact caused by this species (SOUZA; ROCHA; LIMA, 2005).

Nery et al. (2008) studied the recruitment and ecological succession of fouling macrofauna in substrates in the port of Recife (PE) and one of their objectives was to verify the presence of exotic species. The presence of *M. leucophaeta* was then registered and, more importantly, in all the plates this bivalve was the most representative among the organisms found (Cnidaria, Annelida and Crustacea, in addition to Mollusca). In addition, regarding equitability, it has been shown to be low due to the predominance of *Chthamalus sp*. and *M. leucophaeta*, indicating an imbalance in the community.

Regarding its spatial distribution and temporal variation, *M. leucophaeta* is well established in the estuarine areas of Recife, with continuous and more intense recruitment in the summer. A espécie é vista presa a substratos formando agregados densos na região intertidal, onde compete por espaço com *Mytella charruana*, uma espécie nativa (GALEÃO; SOUZA, 2015).

Studying the benthic community of impacted coastal lagoons in Recife and Olinda, Pernambuco, Farrapeira et al. (2009) carried out an inventory of vegetation and epibentonic fauna in the intertidal zone, to assess how environmental changes affected the composition of the biological community. Thus, *M. leucophaeta* was observed as the only bivalve found in the two studied sites, occupying the place where the native species *Mytella charruana* and *M. guyanensis* should be.

In the state of Pernambuco, master's theses have been done studying the spatial distribution and temporal variation (FREITAS, 2009), geographical distribution (CAMPOS, 2010) and reproductive biology (MACIEL, 2011) of *M. leucophaeta*. This shows that the research centers of the universities are concerned with understanding the biology of this bivalve, being able, in this way, to present important information for any measure that is taken by the control organs.

In Rio de Janeiro, Fernandes et al. (2020) carried out extensive field research to evaluate the spread of *M. leucophaeata*, whose only site invaded by the species was the Rodrigo de Freitas lagoon (RIZZO et al., 2014; FERNANDES et al., 2018). In this study, a new record of this mussel is made for the coastal lagoon of Marapendi, where the diversity of haplotypes of this invasive species is high. The fauna associated with this species was also studied at the site.

The rapid expansion of *M. leucophaeta* requires more research on population dynamics and genetic variability of introduced populations, as well as their impacts on native biota (FERNANDES et al., 2020).

FINAL CONSIDERATIONS

Northeast Brazil has three invasive bivalves. In comparison with the south and southeast regions, the northeast presents a significant amount of research on the ecology of the species *I. bicolor* and *M. leucophaeta*, which is very important, because with these results it is possible to track and understand the pathways that make bioinvasions viable. Regarding *P. perna*, although there is a discussion about its supposed introduction in Brazilian waters, the species can be considered invasive in northeastern Brazil. With its registration in the region, research and monitoring must be carried out, in order to understand its population growth and its possible impacts on the local biota.

Since the effects of the introduced bivalves may be different according to the invaded location, special attention is needed by the Brazilian scientific community, not only in the south and southeast, but especially in the northeast region.

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