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Rapid Communication

Range expansion of the Asian green mussel *Perna viridis* (Linnaeus, 1758) to São Paulo, Brazil

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Abstract

Invasion of new environments by fouling organisms is facilitated via artificial substrates. In this communication, we report the occurrence of the Asian green mussel *Perna viridis* on nautical mooring ropes discarded at a voluntary drop off point for end-of-life fishing and nautical gear (EOLFG) in a port area in Ubatuba, northern São Paulo, Southeast Brazil. Individuals were classified as *P. viridis* based on morphological characteristics and were estimated to be less than six months old. We have been performing the characterization of EOLFG (i.e. size, composition, presence of associated fouling organisms) in this location for over 13 months, with this record representing the first documented instance of the green mussel in the state of São Paulo. Given the possibility of competition with the brown mussel *Perna perna*, the only farmed mussel in São Paulo, and the proximity to marine protected areas, urgent monitoring efforts are needed to determine the extent of *P. viridis* settlement in the region, and whether this species is capable of colonizing natural substrates along the Brazilian coastline.

Key words: invasive species, EOLFG, polyethylene, Bivalvia, Mytilidae

Introduction

The Asian green mussel *Perna viridis* (Linnaeus, 1758) (Mollusca, Mytilidae) is native to the northern Indo-Pacific, occurring along the coasts of India and Southeast Asia (Siriwardena 2019). Over the last thirty years, the species has spread to every major ocean, except for the poles (Figure 1A, Supplementary material Table S1). The first recorded incursion of *P. viridis* into the Atlantic was in 1990, in Trinidad (Agard et al. 1992). Throughout the mid to late 1990s, populations were subsequently reported in Venezuela (Rylander et al. 1996), Jamaica (Buddo et al. 2003) and in the US states of Florida (Benson et al. 2001) and Georgia (Power et al. 2004). While these ensuing records may have been the result of natural stepwise larval expansion (Siddall 1980), the initial colonization event in the Caribbean was likely caused by shipping activity, i.e. ballast water and hull fouling (Gobin et al. 2013).

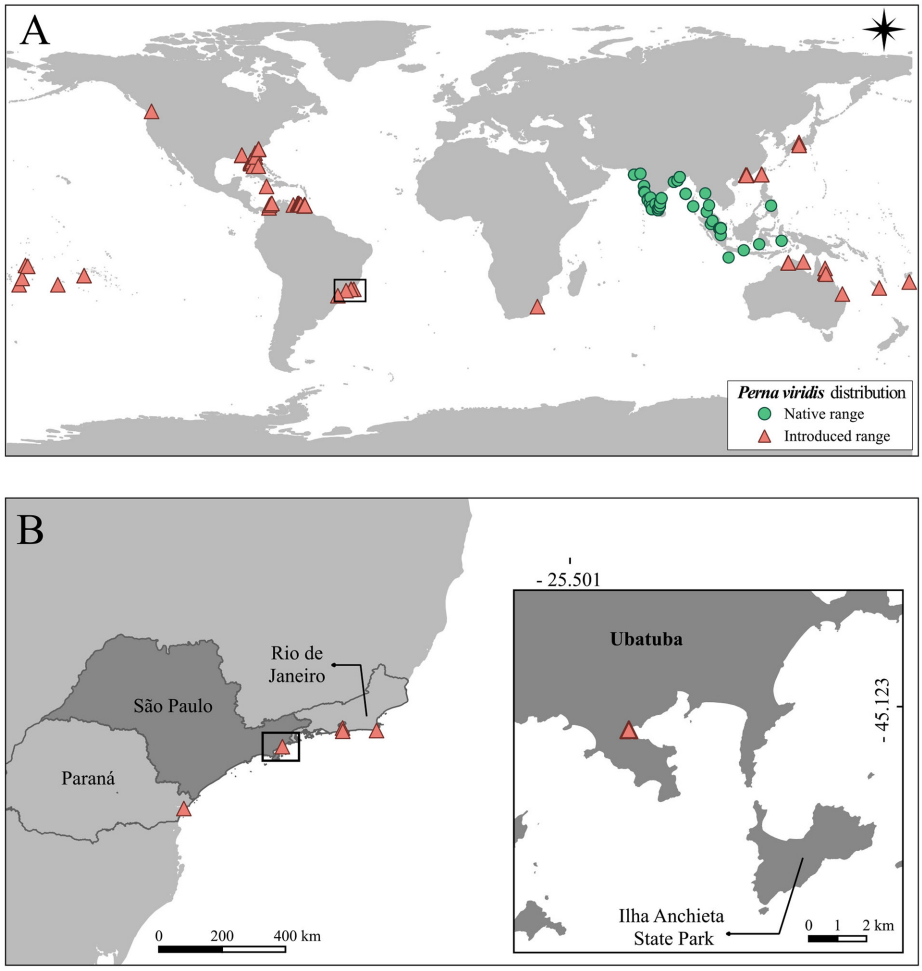

Figure 1. Distribution map for the Asian green mussel *Perna viridis*. (A) Global distribution showing native (green circles) and introduced ranges (red triangles) for the species. Coordinates were obtained from Table S1. (B) Recorded occurrences in Southeast and South Brazil, in the states of Rio de Janeiro, São Paulo and Paraná. Detail of record for the state of São Paulo, city of Ubatuba, in the Saco da Ribeira Pier, in proximity to the Ilha Anchieta State Park. Map by Julia Molina.

Messano et al. (2019) provided the first record of *P. viridis* in Brazil, on experimental plates in Guanabara Bay, Rio de Janeiro. The species has since been reported in two other locations in the country, spanning almost 1000 km: in Arraial do Cabo, also in Rio de Janeiro, on the southeastern coast (dos Santos et al. 2023), and more recently in the Paranaguá Estuarine Complex, Paraná, on the southern coast (Beltrão et al. 2024). The record of the green mussel formerly reported for Fortaleza, Ceará, on the northeastern coast (Regis et al. 2021), has now been positively identified as *Mytella strigata* (Hanley, 1843) (Mollusca, Mytilidae) (Arruda et al. 2024). Regardless, all previous studies reported colonization of artificial substrates; on experimental plates, shellfish lanterns or concrete pillars. The present work details the occurrence of *P. viridis* on mooring ropes, yet another type of artificial structure. These efforts were undertaken by Projeto Petrechos de Pesca (Project Fishing Gear) in Ubatuba, northern coast of São Paulo, Southeast Brazil. Finally, the risks associated with the invasion of this species in the region are discussed.

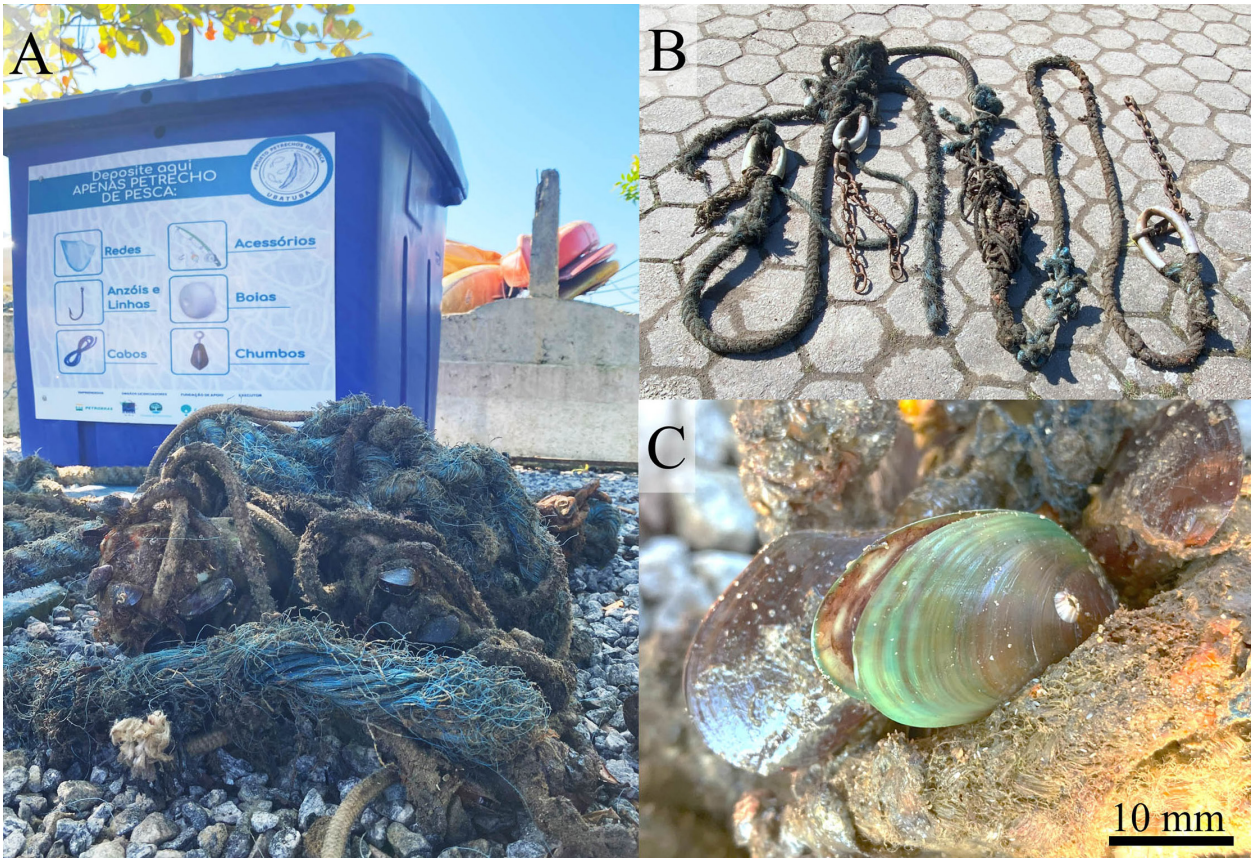

Figure 2. Mooring ropes retrieved by Projeto Petrechos de Pesca in the Saco da Ribeira Pier, Ubatuba, São Paulo, Brazil. (A) Mooring ropes and voluntary drop off point skip. (B) Full view of the mooring ropes, showing attachments. (C) Close-up of *Perna viridis*, with *Perna perna* in the back. Photographs by Debora Ramalho.

Materials and methods

The Saco da Ribeira Pier (SRP) (23.5019S; 45.1234W) is located in a semi-confined cove in the south-central district of Ubatuba, São Paulo, Brazil (Figure 1B). Due to the SRP being the largest port in the city, it was strategically chosen as the location for a voluntary drop off point (VDP), setup by Projeto Petrechos de Pesca in May 2023. The VDP is a plastic skip designed to receive end-of-life fishing and nautical gear (EOLFG) – which can be defined as gear or accessories that are no longer able to fulfill their original purpose due to being old, redundant or damaged (Stolte et al. 2019). EOLFG includes gillnets, trawl nets, buoys and mooring ropes. One of the project's aims is to receive and characterize these materials in relation to their size and composition, and to identify associated fouling organisms. Following standard procedures (see Appendix 1), all organisms are carefully retrieved and preserved in 70% ethanol. Measurements are performed using a digital caliper (MTX, ± 0.02 mm error).

Results

On 5 June 2024, three fresh, distinctively colored green mussels were found attached to a still damp set of mooring ropes which had been deposited in the VDP (Figure 2). Ropes (total length of 15.20 m, 35 mm in diameter, 33.4 kg dry weight) were composed of blue braided polyethylene strands ending

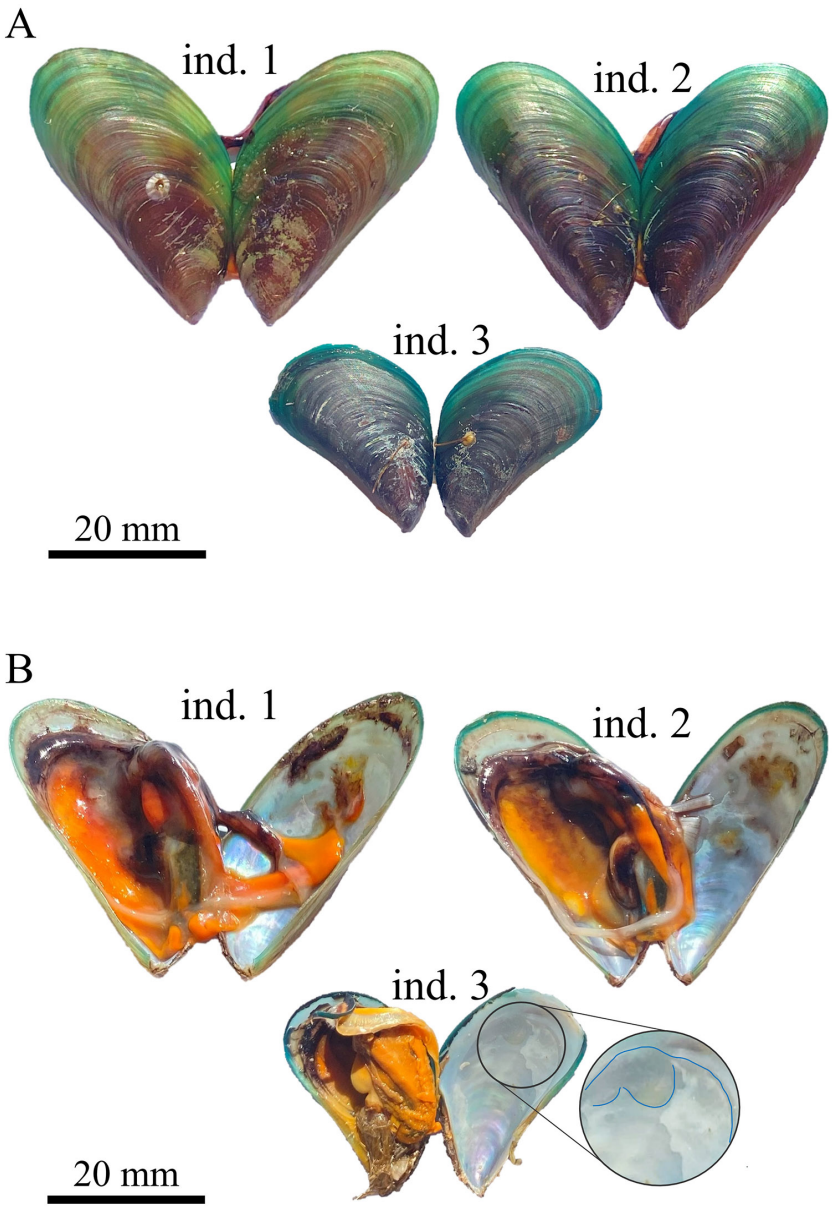

Figure 3. *Perna viridis* individuals collected from mooring ropes in the Saco da Ribeira Pier, Ubatuba, São Paulo, Brazil. (A) External view of the shells, depicting the characteristic green growth lines of this species. (B) Internal view of the shells, depicting the orange gonads of the three female individuals and highlighted detail (in blue) of the kidney-shaped adductor muscle scar and bulging pallial line (individual 3). Photographs by Debora Ramalho and Gabriel Stefanelli-Silva.

in thimbles tied to metallic swivel shackles and chains. This type of rope-chain system is typically used to prevent vessel drifting by attaching a pick-up buoy to an anchor or concrete block on the seabed (Figure S1). Mussels were identified as the Asian green mussel *Perna viridis* (Figure 3); initial diagnostic features were the green coloration of the outer edge of the periostracum and green growth lines, and the bluish pale coloration of the inner surface of the valves. The definitive diagnostic feature was the kidney-shaped scar of the posterior adductor muscle, which pushes out of the pallial line (Siddall 1980) (Figure 3B). Individuals were identified as female based

Table 1. Shell measurements and predicted age of three *Perna viridis* individuals collected from mooring ropes in the Saco da Ribeira Pier, Ubatuba, São Paulo, Brazil. Age estimates are based on McDonald (2012).

	Length (mm)	Width (mm)	Height (mm)	Age (days)
P. viridis 1	43.31	21.32	12.82	180
P. viridis 2	40.04	19.70	12.33	166
P. viridis 3	27.18	15.46	8.71	113

on the bright orange coloration of the gonads (Rosell 1991). Since operation of the VDP commenced in May 2023, no previous observations of this mussel had been recorded.

Shell length (maximum antero-posterior distance), width (maximum ventro-dorsal distance) and height (maximum thickness between closed valves) for the three *P. viridis* individuals are shown in Table 1. Based on growth rate data available in McDonald (2012), the approximate age for individuals 1, 2 and 3 was 180, 166 and 113 days, respectively (Table 1). Age estimates were calculated considering an average growth of 0.24 mm day^{-1} in tropical and subtropical waters. Other fouling organisms associated with these ropes included the fire sponge *Tedania (Tedania) ignis* (Duchassaing & Michelotti, 1864) (Porifera, Tedaniidae), the acorn barnacle *Amphibalanus amphitrite* (Darwin, 1854) (Arthropoda, Balanidae), the rayed pearl oyster *Pinctada imbricata* Röding, 1798 (Mollusca, Margaritidae) and the brown mussel *Perna perna* (Linnaeus, 1758) (Mollusca, Mytilidae). *Perna viridis* #1 had an *A. amphitrite* individual growing on its shell.

Discussion

This study presents the first occurrence of *Perna viridis* in the state of São Paulo, 206 km further south of the original record in Brazil, reported by Messano et al. (2019). Here, we consider how an increase in occurrence records for this species in Brazilian waters could impact the well-established, commercially exploited *P. perna* and the livelihoods dependent on it, and how the Asian green mussel may have reached Ubatuba.

While also non-native, having arrived in the country as a result of the Portuguese trade of enslaved peoples from Africa (de Oliveira et al. 2017), *P. perna* is well established in the local shellfish sector, constituting the only cultivated mussel species in Southeast Brazil (Alves 2016). Farming of *P. perna* in northern São Paulo has been ongoing since the 1980s (Leal 2000) through a family-run, small-scale mode of operation mostly carried out by artisanal fishers and their families (Fagundes et al. 2004; Alves 2016). The detrimental effects of the invasive *P. viridis* to mussel harvesters in Ubatuba are thus twofold: in addition to potentially carrying exotic parasites (Srisuphanunt et al. 2009), the Asian green mussel is capable of displacing pre-established populations of *P. perna* (Vakily 1989; Segnini de Bravo et al. 1998) due to its broader range of tolerance to temperature and salinity (Rajagopal et al. 2006). In the context of competition for substrate in the

marine environment, two additional aspects are worthy of mention: habitats undergoing higher levels of anthropic disturbance are more prone to invasion by exotic species (Byers 2002); and artificial structures offer an advantage for the settlement and growth of invasive fouling organisms (Tyrrell and Byers 2007).

Fouling on artificial hard substrates is frequently reported as a cause for the range expansion of *P. viridis*. In addition to fouling on ship hulls (Huhn et al. 2015), this phenomenon has been reported on oil platforms (DePalma 1968), water cooling pipes (Rajagopal et al. 1991) and floating EOLFG (Gracia and Rangel-Buitrago 2020). Here, we observe a secondary form of ship fouling, i.e. via the polyethylene mooring ropes used by virtually every ship. This is in line with reports of *P. viridis* settling on suspended ropes in shellfish cultivation farms (Sivalingam 1977; Urbano et al. 2005) which also use polyethylene ropes. Since the ropes deposited in our skip were discarded by an undisclosed collaborator, it is not possible to determine the exact settlement location of the three *P. viridis* individuals. However, as collected organisms were still fresh, including live *A. amphitrite* barnacles, and *T.* (*T.*) *ignis* sea sponges which would otherwise have lost their bright coloration due to desiccation, this indicates that the ropes had recently been underwater. Moreover, these heavy rope-chain systems are attached to fixed deadweight anchors (Skop 1988) and left at sea for extended periods, until replacement is necessary, which indicates that the ropes are likely local in origin.

The SRP is the largest and busiest port in Ubatuba, where services of nautical garages, repair and cleaning of vessels, loading and unloading of fishing haul, and operation of recreational vessels and floating fuel stations are provided (CETESB 2018). Such a myriad of nautical activities has resulted in several cases of biological invasions in the marinas within the SRP (Oricchio et al. 2019). Given how Messano et al. (2019) and dos Santos et al. (2023) reported *P. viridis* in the neighboring state of Rio de Janeiro, it is possible that vessels traveling between the two states were responsible for the initial colonization of the Asian green mussel in Ubatuba. Invasions resulting from ship transport are widely reported for mussels of the genus *Perna* (Hicks and Tunnell 1995; Stafford et al. 2007; Huhn et al. 2015), with ports likewise serving as major recipients of invasive species (Drake and Lodge 2004; Seebens et al. 2013; Wan et al. 2021). The particularities of the SRP thus make it an ideal entry point for the invasion of the Asian green mussel.

For the first 13 months of operations, where Projeto Petrechos de Pesca received and characterized 235 mooring ropes in Ubatuba, no *P. viridis* individuals were observed. This could indicate that the mussels reported here are part of an initial population of colonizers. The proximity of the SRP to a protected area such as the Ilha Anchieta State Park (Figure 1B) is a concern given the susceptibility of natural preserves to invasive species (Shackleton et al. 2020) and the costs associated with post-invasion actions of eradication and control (Moodley et al. 2022). To the best of our knowledge, no *P. viridis* have yet been found on the rocky shores of Ubatuba. Continued

monitoring efforts are necessary to determine the extent of the invasion process through fouling on EOLFG, whether the difference in age for the individuals reported here is the product of sequential introductions or local natural reproduction, and whether competition with *P. perna* could be extended to the natural environment. Considering the potential sanitary risks of consuming recently arrived nonnative species, communication with local shellfish producers and consumer information campaigns should be a priority.

Authors' contribution

VCG and GSS were responsible for research conceptualization. DCFR, SMC and GSS were responsible for investigation and data collection. GSS was responsible for specimen identification. SMC was responsible for maintenance, monitoring and methodology concerning the voluntary drop off point, and for characterization of the mooring ropes. JMBM was responsible for processing the data on *P. viridis* distribution. VGA was responsible for project coordination. GSS wrote the first draft and all authors participated in the revision of the manuscript. All authors read and approved the final version of the manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Global distribution coordinates for *Perna viridis* used to assemble Figure 1A. Adapted from dos Santos et al. (2023).
http://www.reabic.net/journals/bir/2025/Supplements/BIR_2025_Stefanelli-Silva_etal_SupplementaryTable.xlsx

Figure S1. Newly assembled mooring rope system.
http://www.reabic.net/journals/bir/2025/Supplements/BIR_2025_Stefanelli-Silva_etal_SupplementaryFigure.pdf

Appendix 1. Protocol for the characterization of fouling organisms associated with end-of-life fishing and nautical gear.
http://www.reabic.net/journals/bir/2025/Supplements/BIR_2025_Stefanelli-Silva_etal_Appendix_1.pdf