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Rapid Communication

First report of the Asian green mussel *Perna viridis* (Linnaeus, 1758) in Rio de Janeiro, Brazil: a new record for the southern Atlantic Ocean

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Abstract

The invasive Asian green mussel *Perna viridis* is native to the Indo-Pacific Ocean but introduction events of this species have been reported from other locations in the Pacific basin (Japan); the Caribbean (Trinidad and northeastern Venezuela) as well as North Atlantic (Florida). In this communication, we report the first record of the bivalve *Perna viridis* in the South Atlantic. Two specimens were found on experimental plates installed at Guanabara Bay (23°S and 43°W) Rio de Janeiro, Brazil in May 2018. Thereafter, a survey was carried out in the surroundings and five others individuals were found. The mussels had on average a length of 48.5 mm ± 29.7; width of 25.1 mm ± 12.2 and height of 16.1 mm ± 9.9. Guanabara Bay is a heavily urbanized and polluted estuary, which houses a large port area with high maritime traffic. Fouling on vessels may be the most likely vector of introduction of *P. viridis*. The occurrence of this species in the Guanabara Bay port area represents a risk to other areas of the Brazilian coast and neighboring countries, connected by maritime trade and recreational vessels. Our findings emphasize the need to implement a monitoring programme for *P. viridis* presence and potential spread in Guanabara Bay and to surroundings areas.

Key words: bioinvasion, invasive mussel, South America, port

Introduction

Events relating to molluskan bivalves introduction and invasion are widely reported, not only in freshwater but also in the marine environment (Ricciardi 1998; Bax et al. 2002). Once established, bivalves can cause severe impacts affecting industries (e.g. clogging pipelines, heat exchange tubes), colonizing aquaculture structures and affecting ecosystem functioning (Orensanz et al. 2002; Sousa et al. 2009). The competitive superiority of introduced bivalves over native species that ultimately supports the high invasive potential of these mollusks has been acknowledged to derive particularly from their life cycle characteristics (Gosling 2015). High fecundity, rapid recruitment and growth, ability to detach and re-attach with byssus, greater ability to colonize a wide range of habitats (natural and artificial), wide physiological tolerance and gregarious behavior are some

of their characteristic that have been described to favor the capacity of bivalves to invade ecosystems (Urbano et al. 2005; Rajagopal et al. 2006; Spinuzzi et al. 2013).

It is well known and widely reported in the literature that port and harbor areas are the main entry points of non-indigenous species, where they are able to colonize artificial and natural substrates (Floerl et al. 2009; Airoldi et al. 2015). The Port of Rio de Janeiro is the third largest Brazilian port in terms of traffic and connectivity. It is located inside Guanabara Bay, a typical estuary that is totally urbanized and suffers high levels of anthropogenic disturbance, resulting from chemical pollution and sewage discharge. Additionally, the domestic and international maritime traffic, including commercial ships, off-shore operational vessels, recreational vessels and maritime public transportation contribute to these disturbances (Soares-Gomes et al. 2016).

The mollusk bivalve *Perna viridis* (Linnaeus, 1758) has been highlighted as a high-risk invader worldwide (Dias et al. 2018). In May 2018, two individuals of *P. viridis* were found attached to experimental plates, installed to test anti-fouling systems (AFS) at Guanabara Bay, Rio de Janeiro, Brazil. Our team has been conducting AFS tests at this experimental facility for over 20 years and the presence of *P. viridis* was never noticed before that detection. The present report expands the occurrence of this species to the south Atlantic and calls attention to the urgent need of implementing a local biosecurity response, monitoring and management programme.

Materials and methods

Following the detection of two *P.viridis* individuals attached to the experimental monitoring plates hanged on a wharf located at Ponta da Areia, Niterói, Rio de Janeiro, Brazil (22.884732S; 43.132099W) (Figure 1), SCUBA surveys were performed in the surrounding areas two weeks after the first record. Visual and underwater inspections were done by two people in the twelve pilings of the wharf and in the nearest rocky shores from the upper intertidal to 1.5 m depth. Two other live individuals were found on the pilings. Six months later, three more individuals were found in a seawall three kilometers away from the wharf (Praia das Flechas, Niterói, 22.9907953S; 43.125437W) (Figure 1). The seven individuals were collected, transported to the laboratory and preserved in absolute alcohol to confirm identification. Shells were measured using a stereoscopic microscope with scale (Zeiss, Discovery V8) and photographs were taken. The specimens were stored for molecular analysis.

Results

The seven *Perna viridis* individuals were recognized due to the uniformly bright green coloration of the periostracum and white coloration of the inside

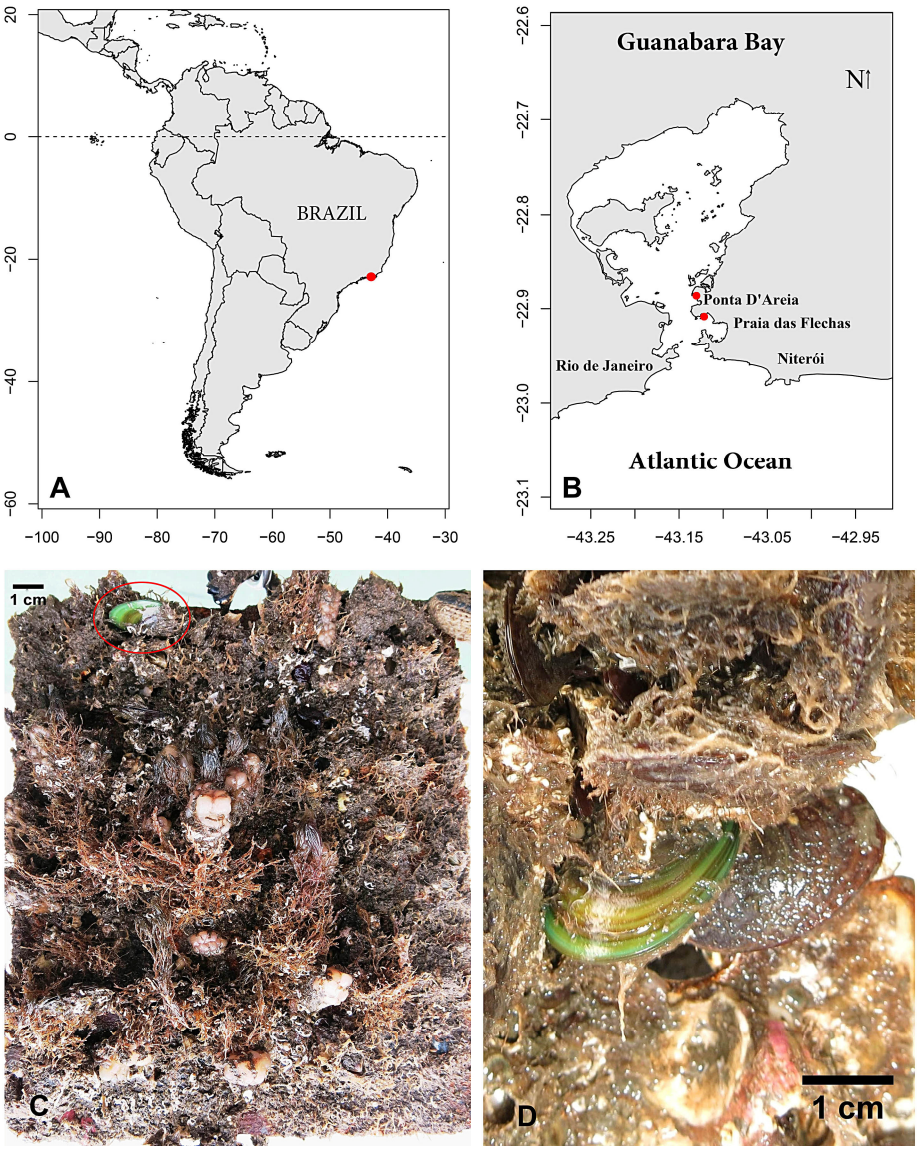

Figure 1. (A) Map showing the south Atlantic (B) and Guanabara Bay, Rio de Janeiro, Brazil, where *P. viridis* was recently found at Ponta D'Areia and Praia das Flechas; (C) *Perna viridis* (shown inside red circle) attached on the experimental plate and (D) *Perna viridis* together with *Perna perna* on the same plate. Photographs by Fabian Messano.

surface of the shell (Figure 2). Additionally, these specimens presented conspicuous morphological features characteristic of *P. viridis,* such as smooth elongated shells with a curved shape and posterior adductor scars extended beyond the pallial line, leaving a muscle scar in a wavier or S-shaped mark. Also it was observed a smooth mantle edges, visible concentric growth rings, the beak curved down (i.e., where the two valves hinge together) and a pair of hinge teeth on the left valve that interlock with a single hinge tooth on the right valve (Rajagopal et al. 2006). The individuals (n = 7) measured in average: a length of 48.5 mm ± 29.7; width of 25.1 mm ± 12.2 and height of 16.1 mm ± 9.9 (Table 1). The shells showed traces of gastropods predation indicating ecological interactions, but until now, the species was not found in natural substrates.

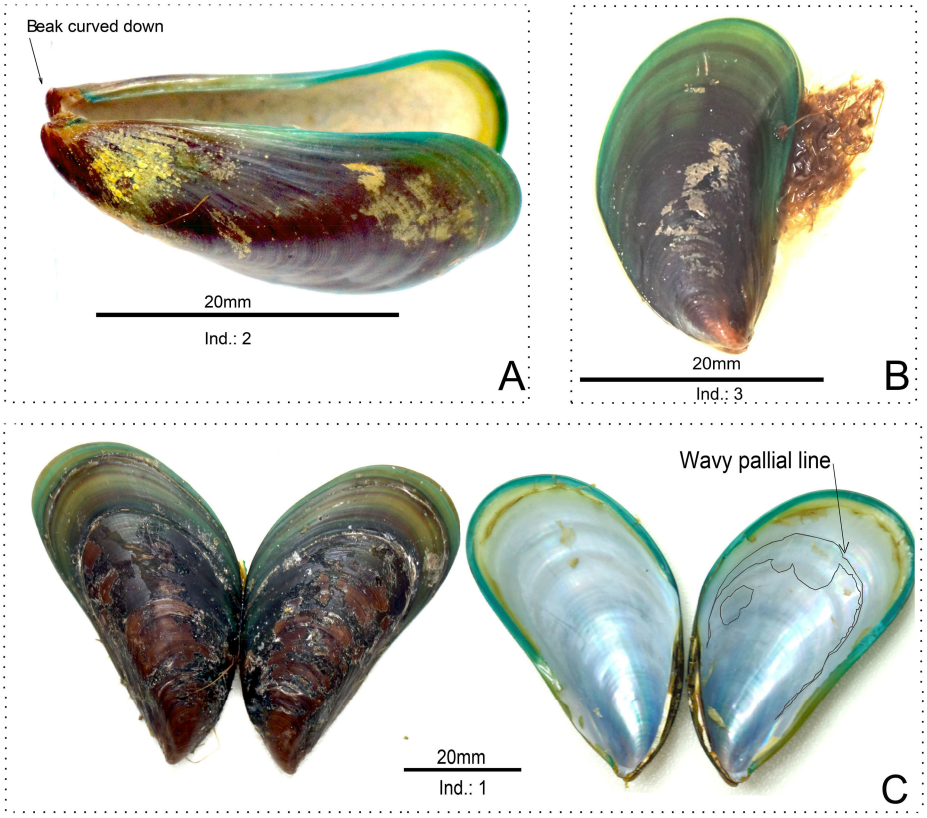

Figure 2. Individuals of *Perna viridis* collected in Guanabara Bay, Rio de Janeiro, Brazil. Photographs by Savio Calazans.

Table 1. Sizes of the shells of *P. viridis* found in Guanabara Bay, Brazil.

P. viridis	Length (mm)	Width (mm)	Height (mm)	Attached to
Individual 1	52.74	26.19	17.33	plate
Individual 2	35.30	19.72	11.91	plate
Individual 3	24.19	14.24	7.65	piling
Individual 4	20.30	13.10	7.00	piling
Individual 5	87.45	39.10	30.5	seawall
Individual 6	28.55	18.99	9.45	seawall
Individual 7	91.25	44.40	28.9	seawall
Average	48.54	25.11	16.11	–
St. Deviation	29.78	12.23	9.91	–

Discussion

Perna viridis is one of three species in the genus *Perna*, native from India to Southeast Asia, including Indonesia and Singapore, but also extending to Hong Kong, Taiwan and southwest China, despite the fact that its origin remains unclear (Siddall 1980; Dias et al. 2018). Other localities in the Pacific basin such as Japan and other southwest Pacific archipelagos are considered part of the introduced range of the species (Hanyu and Sekiguchi 2000; Baker et al. 2007).

The first record of *P. viridis* in the Atlantic basin was at Trinidad, Caribbean Sea observed in the 1990's, but current population distribution is sparse, occurring at discrete points (Gobin et al. 2013). After that, *P. viridis* spread to other areas of Caribbean, including Venezuela (Segnini de Bravo

et al. 1998) and Jamaica (Buddo et al. 2003). Further, *P. viridis* was recorded in 1999 at Tampa Bay (Gulf of Mexico), and have subsequently spread to more locations on the Atlantic coast of Florida where populations became established (Galimany et al. 2018). In 2001, the species was observed in Cairns, Australia, but despite the favorable conditions, the bivalves failed to establish there (Wells 2017). However, in the Atlantic basin, south of the equator, along some 8.000 km of Brazilian coastline, *Perna viridis* has never been recorded prior to this study (Figure 1).

The transportation of fouling species on the hull of vessels is considered a serious biosecurity problem (Williams et al. 2013) and the presence of *P. virdis* in the fouling of ships and other artificial structures is widely reported (Minchin et al. 2016) although ballast water has already been suggested as an invasion vector for this species (Baker et al. 2007; Dias et al. 2018). The port of Rio de Janeiro, located inside the bay, is an important maritime hub and *P. viridis* can be subsequently easily transported to several different locations, not only along the Brazilian coast but also internationally. It is important note that other non-indigenous fouling species have successfully invaded the area, such as the barnacles *Megabalanus coccopoma*, *Amphibalanus reticulatus*, *Amphibalanus eburneus*, *Amphibalanus amphitrite* and *Balanus trigonus*, the bivalve *Isognomon bicolor*, the ascidians *Styella plicata* and *Ciona intestinalis*, the ectoprocta *Schizoporella errata*, the sponge *Paraleucilla magna* and the polychaete *Branchioma luctuosum* (Soares-Gomes et al. 2016 and references therein).

The co-generic of *P. viridis*, *Perna perna*, can be found on several rocky shores of Guanabara Bay (Rizzini-Ansari et al. 2016). Recent evidences showed that the species was introduced during the slave ships traffic between Africa and Brazil in the 15th and 19th centuries and the species has been considered naturalized in the area (Silva et al. 2018). The environmental requirements are similar for *P. perna* and *P. viridis* and they are known to have been both introduced and co-occur in certain regions (Micklem et al. 2016). *P. viridis* is considered a superior competitor, showing higher thermal and salinity tolerance limits than *P. perna* (Rajagopal et al. 2006) and the displacement of *P. perna* by *P. viridis* has been previously observed (Segnini de Bravo et al. 1998). These facts represent critical hazards since *P. perna* is an important economic resource and a key species of several rocky shores in other regions of Brazil (Silva et al 2018).

Early detection is one of the premises of bioinvasion management and prevention, in addition to pre and post border cleaning practices and an efficient anti-fouling system (Davidson et al. 2016). This is remarkably important in areas such as Guanabara Bay where monitoring and regular surveys are strongly recommended (Ojaveer et al. 2014). Our findings emphasize the need of implement a long-term programme for the monitoring of the potential presence of *P. viridis* around Guanabara Bay. Based on the "Predict Age" estimative, a compilation of several growth

rates of *P. viridis* done by McDonald (2012), the size of the individuals found at Guanabara Bay shows that their ages varied between 3 and 12 months (using the centered value – 0.24 mm/day) at the time the mussels were collected. Additional surveys should be conducted to determine if the differences among ages were due to multiple introductions over a short time or to natural reproduction.

Furthermore, future steps should include molecular analysis to shed light on the potential source population of *P. viridis*, surveys to determine if this event was only an incursion, or if the bivalve is present on natural substrates and if so, verify ecological interactions and impacts. Research on marine bioinvasions in Brazil has increased in the last three decades and some important goals have been achieved (Ferreira et al 2009; Rocha et al. 2013). However, it is important to advance the discussion about impacts, eradication and control, since Brazilian governmental decision-makers are currently developing a framework to prevent bioinvasions and the feasibility of strategic interventions as control actions should be carefully analyzed. The information presented in this report (the early detection of *P. virdis*) represent the first step towards best practices for biosecurity strategies.

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