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Original Article

The introduction of *Physa acuta* (Gastropoda: Physidae) on Ilha Grande, Southeast Brazil, from initial stages to an established population

A introdução de *Physa acuta* Draparnaud, 1805 (Gastropoda: Physidae) na Ilha Grande, Sudeste do Brasil, desde os estágios iniciais até uma população estabelecida

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Abstract

This study presents a four-year follow-up of an introduced population of *Physa acuta* Draparnaud, 1805, from initial stages to an established population. This introduction occurred on a small impacted stream of Vila do Abraão, the main village of Ilha Grande (Angra dos Reis, Rio de Janeiro, Brazil). The population size increased during the study, and presented a relationship to environmental factors, especially with rainfall. On the initial stages of introduction prevailed the smaller specimens, but on the overall, predominated the intermediate size classes. After less than a year, *P. acuta* becomes established on this stream and was possibly affecting the other species found on the stream. The information presented here is useful to understand the invasion process of invasive snails, as well as directing conservation efforts.

Keywords: freshwater snail, invasive species, Physidae, Rio de Janeiro, Angra dos Reis.

Resumo

Neste estudo é apresentado um acompanhamento de quatro anos de uma população de *Physa acuta* Draparnaud, 1805, desde os estágios iniciais da introdução até seu pleno estabelecimento. Esta introdução ocorreu em um pequeno riacho impactado da Vila do Abraão, o principal vilarejo da Ilha Grande (Angra dos Reis, Rio de Janeiro, Brasil). A população cresceu durante o estudo, e apresentou uma relação com os fatores ambientais, especialmente a pluviosidade. Nos estágios iniciais de introdução prevaleceram os exemplares menores, contudo no panorama geral, predominaram as classes de tamanho intermediárias. Em menos de um ano de introdução, *P. acuta* se estabeleceu neste riacho, e possivelmente está afetando as demais espécies encontradas no rio. A informação apresentada aqui é importante para a compreensão do processo de invasão de moluscos invasores no Brasil, assim como no direcionamento de esforços de conservação.

Palavras-chave: moluscos de água doce, espécies invasoras, Physidae, Rio de Janeiro, Angra dos Reis.

1. Introduction

Physa acuta Draparnaud, 1805 is a freshwater snail worldwide distributed. Although the type locality is on the Garonne River basin (France) (Paraense and Pointier, 2003; Paraense, 2011); it was suggested a North American origin for this species (Dillon Junior et al., 2002). Other authors corroborated this idea (Taylor, 2003; Lydeard et al., 2016; Vinarski and Eschner, 2016), then the original description was possibly made when the species were already introduced in Europe, and now it is widespread (Taylor, 2003; Paraense and Pointier, 2003; Vinarski, 2017), including natural reserves and reservoirs (Kock and Wolmarans, 2008; Miyahira et al., 2020). The systematic and taxonomy of Physidae is not well resolved, and this species was also called *Haitia acuta* (Draparnaud, 1805) (Taylor, 2003; Roll et al., 2009) and *Physella acuta* (Draparnaud, 1805) (Smith, 1989; Cope and Winterbourn, 2004; Semenchenko et al., 2008; Vinarski, 2017). In this study, it was used *Physa acuta* following Wethington and Lydeard (2007) and Ebbs et al. (2018).

The first record in Brazil dates from 1966, under the name *Physa* (*Physella*) *cubensis* Pfeiffer, 1839, on a small pool in Instituto Oswaldo Cruz, Rio de Janeiro state (Leme, 1966;

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Paraense and Pointier, 2003). After that, the species were recorded in other states of Brazil (*e.g.*, Santos et al., 2012, 2016; Miyahira et al., 2020). A brief mention of *P. acuta* on Ilha Grande was done by Miyahira et al. (2010) without any further information. Ilha Grande is a continental island located in the south of Rio de Janeiro state (Brazil) and has important remnants of the Atlantic Rainforest, a global hotspot (Myers et al., 2000; Colombo and Joly, 2010). There are records of other freshwater non-native molluscs on Ilha Grande: *Melanoides tuberculata* (Müller, 1774), *Ferrissia fragilis* (Tryron, 1863), *Biomphalaria tenagophila* (d'Orbigny, 1835), and *Omalonyx matheroni* (Potiez and Michaud, 1835). Despite these two last species were native elsewhere in the state of Rio de Janeiro, their local introduction was observed or inferred to Ilha Grande. There are also some native molluscs reported to the island: *Uncancylus concentricus* (d´Orbigny, 1835), *Gundlachia ticaga* (Marcus and Marcus, 1962), and *Pisidium punctiferum* (Guppy, 1867) (Santos et al., 2007, 2009, 2010; Miyahira et al., 2010; Lacerda et al., 2011, 2015; Braga et al., 2014).

The spread of *P. acuta* was usually related to aquarium trade (Duggan, 2010), but there were other possibilities as plants and goods trade, as also a long-distance travel bird-mediated (Vinarski, 2017). This wide distribution raised attention to how this snail was interacting with the new habitat and native species. The population of *P. acuta* in a new habitat can attain high densities, possibly causing impacts on native fauna (Cope and Winterbourn, 2004; Albrecht et al., 2009; Zukowski and Walker, 2009; Núñez, 2010; Vinarski, 2017; Früh et al., 2017). Furthermore, introduced freshwater snails were also linked to the dispersion of parasites (e.g., Font, 2003; Paula-Andrade et al., 2012; Mitchell and Leung, 2016; Ebbs et al. 2018). On nearby continental areas, other physids were already found parasitized (Thiengo et al., 2004), and on Ilha Grande, *M. tuberculata* was found infected by *Centrocestus formosanus* (Nishigori, 1924) (Ximenes et al., 2017).

The main goal of this work is to detail the introduction of *P. acuta* in Ilha Grande (Angra dos Reis, Rio de Janeiro, Southeast Brazil), and also to give data on the population dynamics of this species, including the initial stages of invasion.

2. Material and Methods

The population was recorded on a human-impacted stream on Vila do Abraão, the main village of Ilha Grande (Angra dos Reis, Rio de Janeiro, Brazil) (Figure 1), where other non-native species were already recorded (Santos et al., 2007, 2010). A continuous general snail monitoring study was conducted from 2006 until 2013. The monitoring of *P. acuta* population was done approximately bi-monthly from February 2009 until November 2013, totalizing 27 sampling events.

We divided the surveyed stream into eight collecting stations (CS); each station had approximately 30m in length and was continuous with each other. The collecting station 1 (CS1) was the most upstream and collecting station 8 (CS8) was the most downstream, near stream mouth (Figure 1). This division was established to analyze the expansion and distribution of the snail on the stream. Three collectors using a handled metallic scoop searched for the snails for 15 minutes in every favorable environment. All collected snails were placed in plastic pots and taken to the laboratory, where the snails were identified, measured, and counted. The specimens collected from February 2009 to February 2010 were measured (width and height) with a 0.05 mm precision caliper, accounting for 434 specimens. The measured snails were divided into nine 1 mm size classes (CL) based on shell height, *i.e.* CL1 from 0.01 to 1.00 mm

Figure 1. Map of the Vila do Abraão (Ilha Grande, Angra dos Reis, Rio de Janeiro), highlighting the studied stream (blue line) and the eight collecting stations (CS; red dots).

until CL9 from 8.01 to 9.00 mm. The relationship between width and height was done by linear regression.

Monthly rainfall data were obtained from INMET (2021) for the city of Rio de Janeiro, as there is not available data for Angra dos Reis in the studied period. The rainfall data used was from the previous month of the collecting month to ensure the proper signal of rainfall, since sometimes sampling was done at the beginning of the month. Water temperature, river depth, pH, and conductivity were taken in each CS, and a mean was calculated for each collecting month. Those variables and rainfall were used on a Multiple Regression to determine the relationship of those factors with the abundance of *P. acuta*. Out of the 27 samplings events, four were removed from the analyses because we have some failures on the measurements, resting 23 months.

Voucher specimens were deposited at the Malacological Collection of the Universidade do Estado do Rio de Janeiro (UERJ). The study was performed under the legal authorizations (Sisbio10812-1, INEA 18/2007).

3. Results

The snails were monitored on this stream since 2006 (Santos et al., 2007), and until January 2009, *P. acuta* was not present. Thus, the monitoring of this population was done since the initial stages of the introduction. As expected for a recent introduction, few individuals (only three) were found at first sightings (February and April 2009) (Figure 2). The species was limited to CS1, and the snails were found attached to water hyacinth (*Eichornia* sp.). In April 2009, the species began to spread in the stream and were found from CS2 to CS5 (Figure 3), but the species were still rare (10 specimens). After September 2009, *P. acuta* was spread over all the studied area, and the population increased considerably and continuously until February 2010 (142 specimens in September 2009 to 201 in February 2010), and then, drops down (3 in April 2010). After that, were observed constant fluctuations in the population (Figure 2). The highest abundance was observed in October 2012, with 749 specimens. Despite the initial observation at CS1, the higher abundances were observed at the intermediate CS (CS3-CS5) (Figures 3 and 4). The lowest values of abundances were observed on the final stretch of the stream (CS7 and CS8), and the intermediate values at CS1, CS2, and CS6 (Figure 4). The abundance variation along the time was different in each CS (Figure 3). The three first CS presented the highest values from middle to the end of the monitoring, on the intermediate CS (CS4 and CS5) the population size oscillated along the time, and on the last CS (CS6-CS8) exhibited the lower values, with a higher peak around August and October 2010.

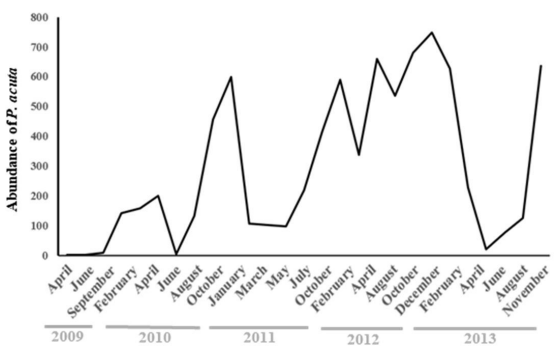

Figure 2. Variation of the total abundance of *Physa acuta* in an impacted stream of Ilha Grande.

The width of *P. acuta* ranged from 0.54 to 5.10 mm, mean 2.67 ± 0.76 mm; and height from 0.61 to 8.05 mm, mean 4.49 ± 1.24 mm. The two measures had a significant (p=0.0001) and high linear relationship with R^2 = 0.86 (Figure 5).

The overall size class distribution was bell-shaped with a prevalence of the intermediate size classes (CL4 to CL6) (Figure 6). The size class distribution over time (2009-2010) presented initial colonization by medium to large-sized specimens (CL7 in February 2009, and CL5 in April 2009) (Figure 7). In June 2009, the small specimens were first observed. After that, a cohort can be observed that developed in the following months until it vanished in April 2010, and the remaining snails were small.

The variation of the environmental variables was presented on Figure 8. The multiple regression showed a relationship of *P. acuta* abundance with environmental factors (R^2 = 0.50, F = 3.14, p = 0.04), the relationships of abundance with rainfall (R^2 = 0.11, p = 0.008), deep (R^2 = 0.09, p = 0.05) and temperature (R^2 = 0.07, p = 0.03) were significant, but with low correlation values.

4. Discussion

Physa acuta was already reported to the south of Rio de Janeiro, in Mangaratiba, Paraty, and Angra dos Reis (Thiengo et al., 2001, 2004) and was probably introduced on Ilha Grande through one of those localities. Santos et al. (2007) suggested the same routes of introduction for *M. tuberculata* and *B. tenagophila* that arrived in the same stream in 2005. In Vila do Abraão, there are several hostels, some of them including small artificial ornamental lakes. The studied stream is narrow and shallow, and macrophytes were not common. The *Eichornia* sp. specimens that were found together of *P. acuta*, was also the first sighting on this stream. After that, this macrophyte does not become established on the stream, in contrast to the snail. It is possible that during heavy rainfalls, a nearby ornamental lake overflowed, releasing these two species on the stream. *Physa acuta* was also found attached to other marginal aquatic vegetation, stones, and leaf litter, suggesting flexibility in habitat requirements, as already suggested by Dillon Junior et al. (2002).

The population of *P. acuta* becomes established on this stream in less than a year. After the initial growth, the population fluctuations were probably related to rainfall as indicated by multiple regression. The analysis of the abundance and the rainfall suggests an inverse relationship between these two variables. A rise in rainfall (usually from November to March), was usually followed by a population drop. However, the population was always able to recover and flourish after the rainfall and stream water

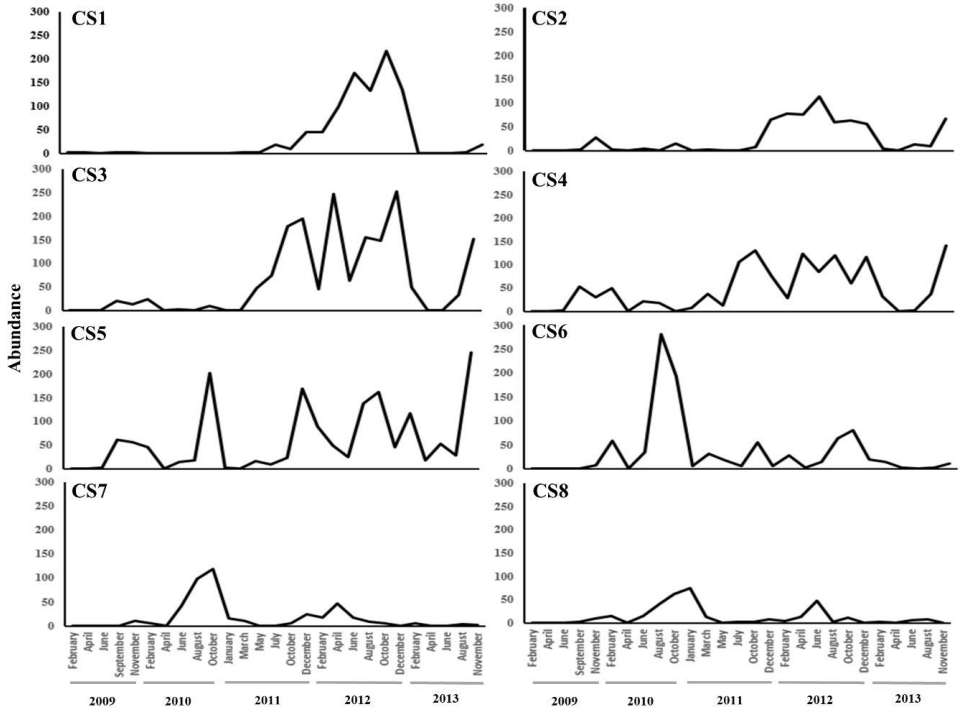

Figure 3. Variation of the abundance of *Physa acuta* in the eight collecting stations (CS) that was established on an impacted stream of Ilha Grande, along the monitoring time.

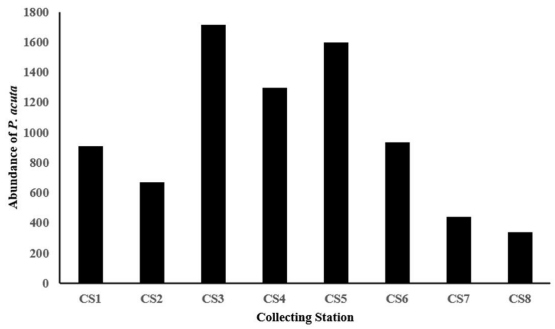

Figure 4. The overall abundance of *Physa acuta* on the eight collecting stations (CS).

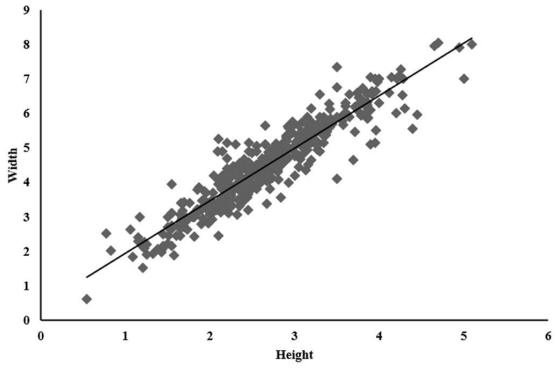

Figure 5. Relationship of shell height and width of *Physa acuta* from Ilha Grande.

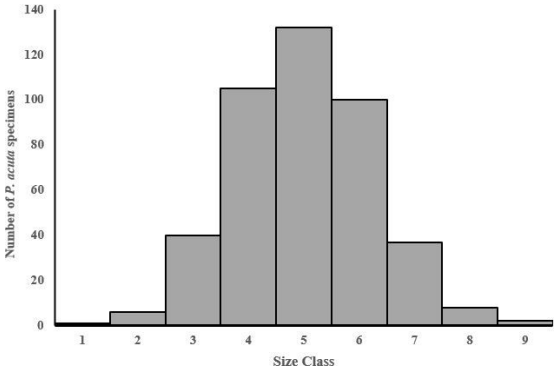

Figure 6. The overall size class of *Physa acuta* representation found on the population of Ilha Grande.

level decreases. Gulanicz et al. (2018) demonstrated the high physiological tolerance of *P. acuta* to these conditions. The rainy season of 2012 has a lower rainfall volume than the other observed years (2010, 2011, and 2013; in 2009 the population is not completely established), and consequently there was a smoother decrease in population size. Other freshwater snails were also influenced by the rains and it can be an important factor especially on small streams (O'Keeffe, 1985; Freitas et al., 1987; Woolhouse and Chandiwana, 1989; Thomas and McClintock, 1996), but the response to drying was species-specific and depends on several factors (McMahon, 1983; Weir and Salice, 2012). The modifications promoted by the man on the stream of Vila do Abraão, like removal of marginal

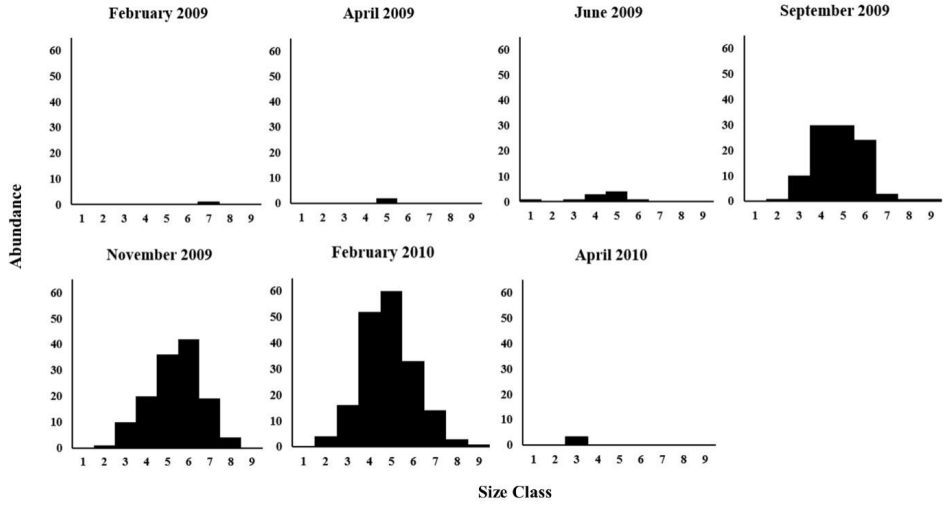

Figure 7. Population variation of *Physa acuta*, divided in size class, through the time in Ilha Grande. Feb = February, Apr = April, Jun = June, Sep = September, Nov = November.

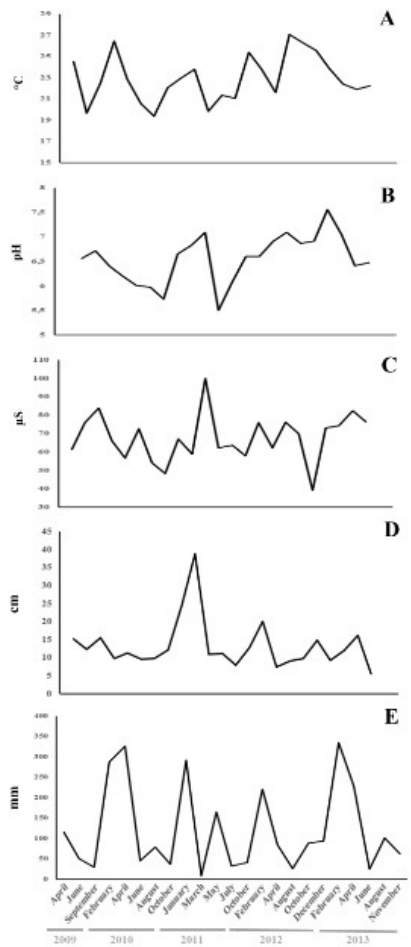

Figure 8. Variation of environmental variables on the impacted stream of Vila do Abrãao. For rainfall was used the data from the city of Rio de Janeiro. A – water temperature, B – pH, C – conductivity, D – water deep, and E – rainfall.

vegetation and rectification, potentialize the effect of the rains. *Physa acuta* can reproduce more than a time per year, and a disturbance in the habitat can be a trigger for reproduction (Dana and Appleton, 2007). Moreover, this species has a rapid juvenile growth and attain maturity very quickly (Thomas and McClintock, 1996), also collaborating for the rapid colonization (initial and after a stochastic event). Those features were good strategies for an invasive species and allow rapid recovery after heavy rainfalls. Soon after the introduction (June 2009), it was observed small specimens at this stream indicating that the population was already reproducing on the stream, and after the first heavy rainfall episode (April 2010) it was also observed those specimens, indicating a quick recovery.

The evaluation of the CS independently indicated different behaviors in each station. Despite the initial introduction on CS1, this station not supported the highest abundance along the time. The first two CS only attained higher abundances after the middle of the monitoring. The CS3 developed a similar pattern but with higher abundances. This last CS, as also CS4 and CS5 supported the first peak of the *P. acuta* population in February 2010. *Physa acuta* was usually found on the intermediate collecting stations (CS3-CS5), probably due presence of some aquatic vegetation on margins, and small marginal pools. The last CS (CS5-CS8) supported the second peak (October 2010) of the population and most of those CS presented the highest values in this month. Those CS (expect by CS5) not presented higher values on other months. The last CS (CS7-CS8) has some marine influence and thus not the ideal habitat for a *P. acuta* population. The population found on this stretch of the river was possibly carried by the current to the last CS, especially on heavy rain episodes. This was clear in January 2011, when a great part of specimens was found on CS8, but not become largely established on this CS, as was observed in the following months. Although physids can present some resistance to a small increase in salinity (Richards, 1929; Kefford and Nugegoda, 2005).

Stockwell et al. (2011) demonstrated that *P. acuta* was sensible to salinity; the survival declines after 7º/oo, and after 9º/oo any snails survive.

Physa acuta attained high population sizes and occurs with other molluscs on this stream like *M. tuberculata*, *B. tenagophila*, *G. ticaga*, *O. matheroni*, *F. fragilis,* and *P. punctiferum* (Santos et al., 2007, 2010; Lacerda et al., 2011; Miyahira et al., 2010; Braga et al., 2014). The effect of *P. acuta* over the other molluscs was not evaluated in this study, but a negative effect of the invasive *M. tuberculata* over *P. punctiferum* was previously observed on the same stream (Braga et al., 2014). There were reported negative effects of *P. acuta* over native species (Zukowski and Walker, 2009; Früh et al., 2017), and it can be of concern on Ilha Grande, especially if the species spread to more preserved streams of the island.

The measurements of *P. acuta* were closely related, and not seems that *P. acuta* changes the growth effort, as the increase of the two measures occurred constantly during the time.

Long-term studies were recognized as a keystone to understanding ecological processes and dynamics (*e.g.*, Jackson and Füreder, 2006; McCarthy et al. 2006). Jackson and Füreder (2006) considered long-term studies those older than five years, our study almost accomplish this period, but regardless of the period helped to understand the introduction process of this species since the population was accompanied since the initial stages of colonization. Moreover, most long-term studies of freshwater invertebrates dealt with arthropods (Scarsbrook et al., 2000; Resh et al., 2005; Jackson and Füreder, 2006), although there are few long-term studies targeting mollusc species (*e.g.* Strayer and Malcom, 2006). The longevity of the study is also important considering conservation efforts as, for example, if removal of *P. acuta* would be considered, it will be probably more successful if done after a heavy rainfall, when the population became smaller. Thus, the information provided here is useful in future studies of this invasive species and of the invasion process of freshwater snails.

It was probable that the introduction of *P. acuta* in Ilha Grande was human-mediated. The stream was bordered by houses along with all the studied extension. Other non-native molluscs introductions on this stream were related to aquarium trade (Santos et al., 2007) and it was suggested that *P. acuta* used a similar pathway. Although the initial colonizers probably previously lived in an artificial lake, plants (and snails hitchhikers) might have been acquired from an aquarium store. The control of goods that enter the island was essential to avoid future introductions.

In a year *Physa acuta* became established and spread on an already impacted stream on Ilha Grande. The evaluating of *P. acuta* populations since the initial stages of the colonization process was essential to understanding the invasion process of this species. This species was widespread not only in Brazil but in several other countries. The data presented here can be used to mitigate the effects of the spread of *P. acuta*, as also on future conservation efforts.

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