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ECOSYSTEMS

Expansion of *Sinotaia quadrata* (Mollusca: Gastropoda: Architaenioglossa: Viviparidae) in two major rivers from Argentina

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Abstract: Invasive non-native freshwater mollusks are a growing concern in South America, with 16 species already recorded in the region. Among them, *Sinotaia quadrata* has only been documented in Argentina, for the first time in the Punilla Valley, Córdoba (2009) and La Plata, Buenos Aires (since 2015). In this study, we report the presence of *S. quadrata* in two additional areas, the Río de la Plata River and a stream (unnamed) in the Paraná River basin, two of the most significant rivers in South America, located in the provinces of Buenos Aires and Entre Ríos, respectively. These new records confirm the invasive nature of this species, which has also been identified in Europe, the United States, and Africa in recent years. The findings of this study highlight the need for continued monitoring and management of invasive species in South America's freshwater ecosystems.

Key words: Conservation, dispersion, invasive species, Río de la Plata River, Paraná River.

INTRODUCTION

Biological invasions are a major threat to nature, causing significant impacts such as biodiversity losses, economic implications, and the spread of diseases (Diagne et al. 2021). An invasive species is one that has been introduced by humans outside its natural geographic range, can support a self-sustaining population in the new ecosystem, exhibiting dispersal, and has evident environmental and socio-economic impacts (UICN 2019, Darrigran et al. 2020, IPBES 2023). The Globalization has led to a substantial increase in the dispersion of these species, particularly in aquatic ecosystems where the number of invasive species has risen in recent decades due to their close association with human activities (Hulme et al. 2008, Hulme 2009, Clusa et al. 2017). Mollusks are not exempt from these dispersals, and in South America, 86 non-native species have been detected, including 16 freshwater species (11 gastropods and 5 bivalves) (Darrigran et al. 2020). The origins of these non-native freshwater species are diverse, with the majority (9) being Asian. Among these species, some exhibit invasive characteristics, notably *Corbicula fluminea* (Müller, 1774), *Limnoperna fortunei* (Dunker, 1857), and *Melanoides tuberculata* (Müller, 1774) (Darrigran et al. 2020).

In Argentina, nine out of the 16 freshwater no-native species were documented in natural environments, and one is held in captivity. Among these nine species, *Sinotaia quadrata* (Benson, 1842) so far only recorded in the country, with no known occurrences in other South American countries. The species is native to Asia and has been detected in two distant areas of Argentina, separated by 820 km, Córdoba (2009) (Ovando & Cuezzo 2012) and La

Plata, Buenos Aires (2015) (Ferreira et al. 2017) (Figure 1). Also, the species has been identified in recent years in Europe (Cianfanelli et al. 2017, Arias et al. 2020, Quiñonero-Salgado et al. 2022), the United States (O'Leary et al. 2021), and South Africa (Miranda et al. 2022), establishing itself as a non-native species with the ability to adapt to various environments, which can turn it into a potential invasive species. While in its native region of Taiwan, this species is known to serve as a host for metacercariae associated with echinostomiasis, a food-borne, intestinal, zoonotic, snail-mediated parasitosis caused by digenean trematodes of the family Echinostomidae (Graczyk & Fried 1998), no specimens infested with digeneans have been recorded in Argentina.

The taxonomic status of *Sinotaia* Hass, 1939 is unclear and recent efforts to revise the taxon show evidence for synonymizing many previously recognized species within the genus with *S. quadrata* (Ye et al. 2021). In Argentina, Rumi et al. (2019) conducted a molecular study on populations from Córdoba and La Plata and confirmed that both belong to the same entity, assigning the identification to *S. quadrata*.

Sinotaia quadrata, the sole representative of the family Viviparidae Gray, 1847 (Architaenioglossa) in South America is a dioecious, ovoviviparous, and sexually dimorphic species commonly found in the mud or silt of

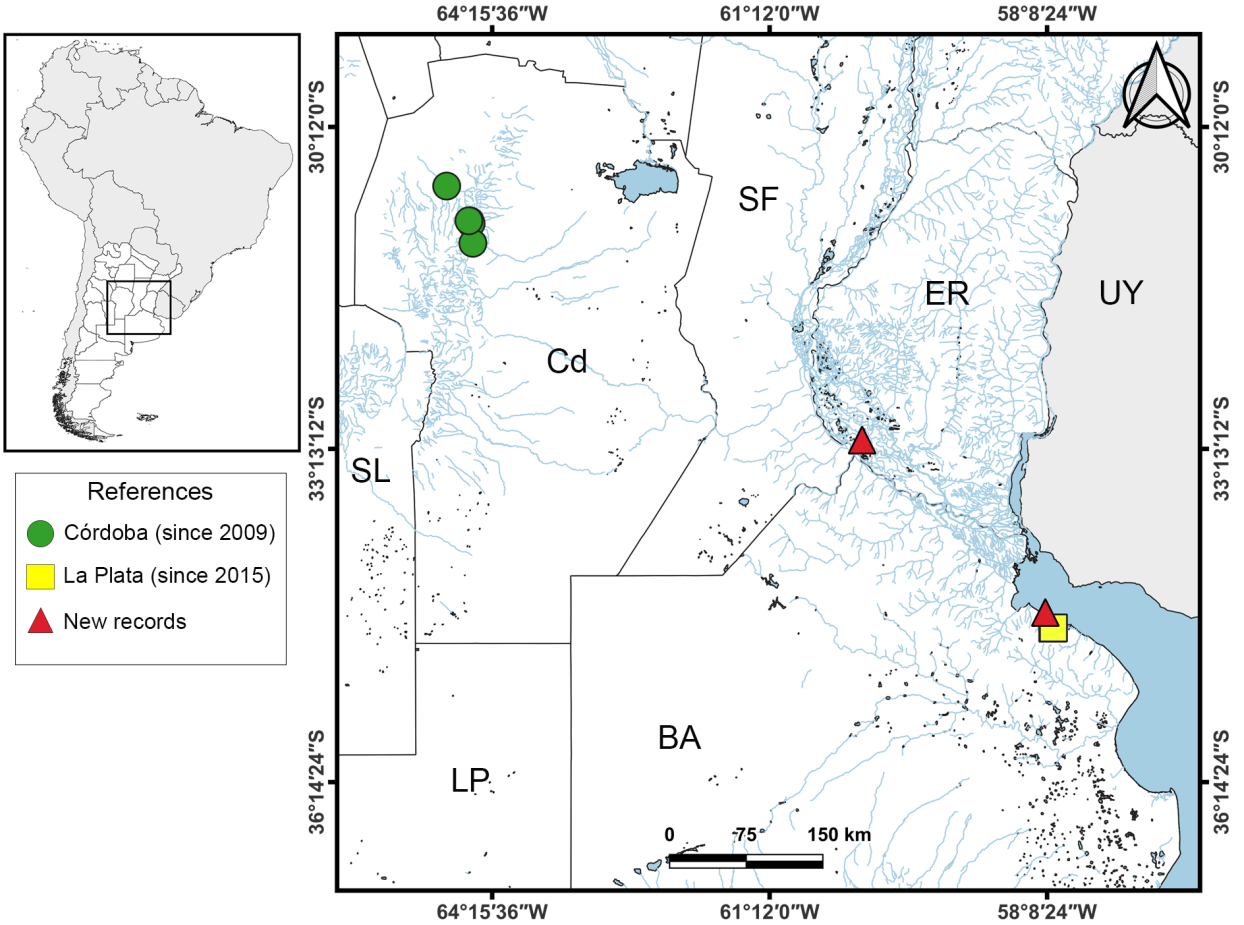

Figure 1. Records of *Sinotaia quadrata* in Argentina. Provinces: BA: Buenos Aires; Cd: Córdoba; ER: Entre Ríos; LP: La Pampa; SF: Santa Fe; SL: San Luis. UY: República Oriental del Uruguay. Maps Source: QGis 3.34.0-Prizren.

lakes, ponds, rice paddies, irrigation canals, and streams (Ovando & Cuezzo 2012). In Argentina, it is found in artificial environments in Córdoba and in small, even highly contaminated streams in Córdoba and La Plata.

In this work, we report the discovery of two new records for the detection of this snail in the provinces of Entre Ríos and Buenos Aires. These findings are significant as they represent environments very different from where the snails have previously recorded, potentially impacting the native mollusk fauna.

MATERIALS AND METHODS

The field collections along the coast of the Río de la Plata River, Punta Lara beach, Ensenada, Buenos Aires (34°46'47.48"S; 58°1'11.05"W) (Figures 1 and 2) were carried out between April and May 2023. The survey covered an 8-kilometer stretch of coastline, from the roundabout at the entrance of Punta Lara beach (34°49'7.79"S; 57°58'1.35"W) to the Capitán stream, located within the Punta Lara Natural Reserve -RNPL- (34°46'38.10''S; 58°2'6.06''W) (Figure 2). At the points on Punta Lara beach where the

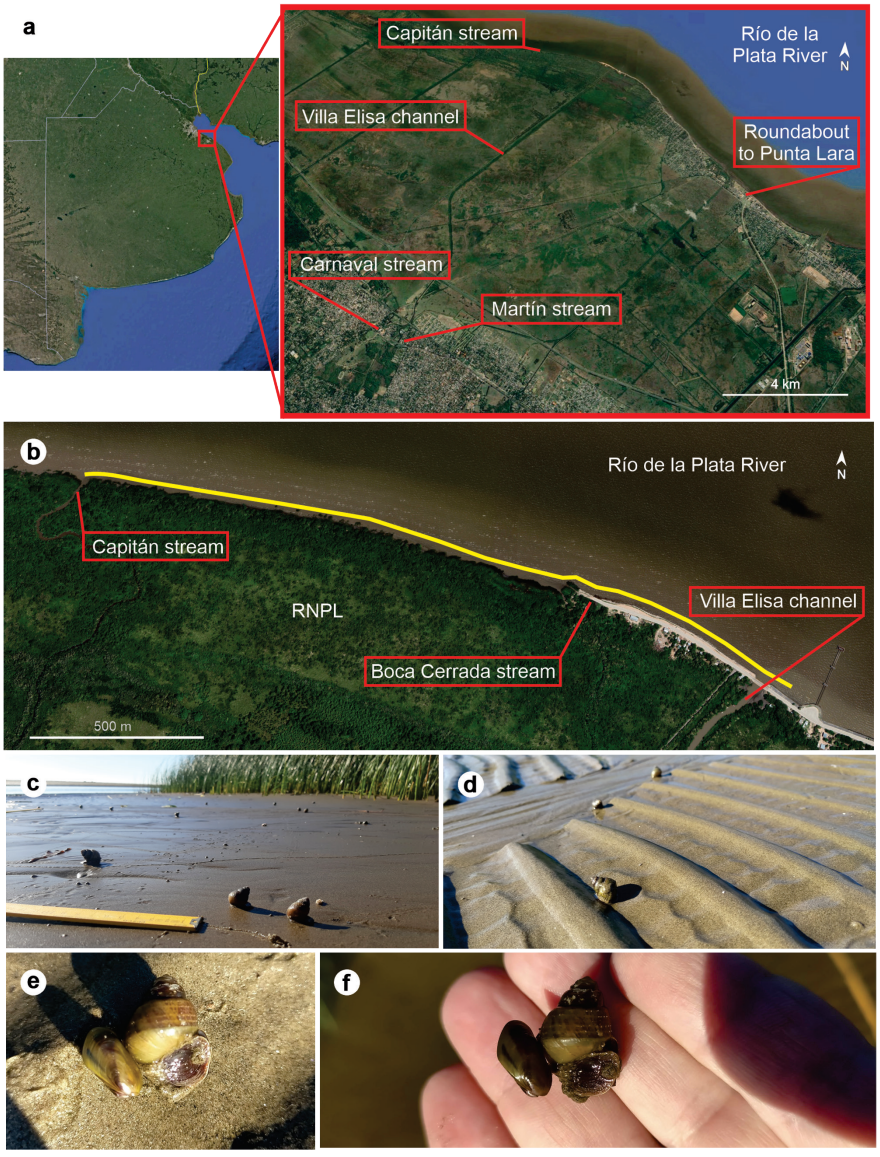

Figure 2. a: Historical records in the city of La Plata (Carnaval stream), and an 8 km transect on the Río de la Plata River conducted in May 2023 from the roundabout to Punta Lara up to Capitan stream (Ensenada); b: Transect (in yellow) conducted from the Capitán stream to the mouth of the Villa Elisa channel; c-d: *Sinotaia quadrata* on the coast of the Río de la Plata River; e-f: *Limnoperna fortunei* on *S. quadrata*. Maps Source: Google Earth.

species was recorded, six 1 m² quadrants were surveyed, three underwater and three at the interface between water and dry land, along a 100 meter transect. The substrate was sieved, and individuals were collected (Figure 2). Additionally, densities were estimated in other quadrants, using photography (counting carried out by one person). The specimens collected during this study have been carefully preserved and deposited in the malacological collection of the Museo de La Plata (MLP-Ma 16099 and 16100) were relaxed in menthol, preserved in alcohol, and then measured (by digital caliper) for the total length of the shell. Soft parts were extracted, and sexes were identified.

Previously, a sample had been collected by other colleagues and donated to the MLP collection, from streams (unnamed) in the Paraná River Delta (province of Entre Ríos) near to the provincial boundary of Santa Fe, Entre Ríos, and Buenos Aires in January 2018 (33°08'21.2"S; 60°10'41.8"W). Specimens were recorded as MLP-Ma 16101 (Figure 1).

RESULTS AND DISCUSSION

The *Sinotaia quadrata* specimens recorded in both provinces match with the anatomical description provided by Ovando & Cuezzo (2012). Adult males exhibited the copulatory organ on the right tentacle (Figure 3a), and adult females showed offspring at different developmental stages inside the brood pouch (Figure 3f). In juvenile specimens, periostracal hairs were

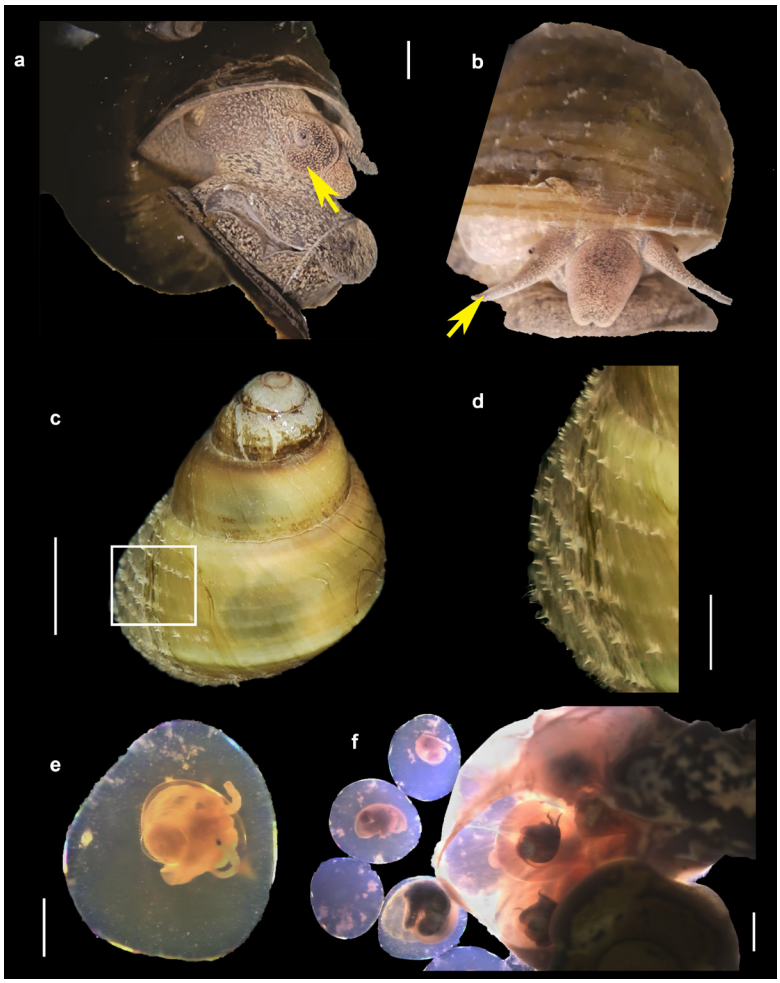

Figure 3. ***Sinotaia quadrata*****. a: Adult male; b: Adult female; c: Juvenile with periostracal hairs on the shell; d: Detail of periostracal hairs; e-f: Eggs. The yellow arrow indicates the right tentacle, curved in males and straight in females. Scale bar: a, b, d, f: 2 mm; c: 5 mm; e: 1 mm.**

observed on the shell (Figure 3c, d). Due to the material collected in Entre Ríos lacking information collected in the field, it was not possible to estimate the density. The individuals recorded in Punta Lara were found along a 100-meter transect parallel to the coast, near the mouth of the Boca Cerrada stream (34°46'46.49"S; 58°1'11.23"W). The specimens averaged a total length of 17.4 mm, with a minimum of 10.9 mm and a maximum of 26.3 mm. The average density found (both in quadrats and with photography) was 21.4 ind/m² (SD: 34.4). The average density found in the quadrants was minor, 7 ind/m² (SD: 3.7); sexual proportion 4:3 (females/males). Meanwhile, using photography, an average density of 50 ind/m² was calculated (SD: 53.5). These quadrant average densities are much lower than those found in La Plata in the Carnaval stream (55 ind/m²) (Ferreira et al., 2017), Italy (90 ind/m²) (Cianfanelli et al. 2017), and South Africa (1074 ind/m²) (Miranda et al. 2022). While the density estimated through photography was like that found in La Plata. Additionally, a single specimen was recorded at the mouth of the Villa Elisa channel (34°46'56.21"S; 58°0'38.29"W, about 300 meters from the previous site, Figure 2) along a perpendicular 100-meter transect.

The new record for the Río de la Plata River is located approximately 10 km from the previous record in 2015 in the Carnaval stream, a watercourse near the city of La Plata, which converges into the Villa Elisa channel that flows into the Río de la Plata River within the RNPL (Figure 2), and 830 km from the records of Córdoba. Surveys conducted from 2013 to the present in the RNPL, both along the coast of the Río de la Plata River and in internal environments such as wetlands and streams, have recorded 23 species of freshwater mollusks (de Lucía et al. 2023a). However, the species in question had not been recorded until now (de Lucía et al. 2023a), indicating its entry of this species into the RNPL is recent (previously to field work). This new finding adds an invasive species to the Río de la Plata River within the RNPL, where three Asian-origin bivalves have already been cited: *Limnoperna fortunei*, *Corbicula fluminea*, and *Corbicula largillertii* (Philippi, 1844) (Darrigran et al. 2020, de Lucía et al. 2023a). In some specimens collected from the Río de la Plata River, it is already observed that *L. fortunei* uses the shell of *Sinotaia quadrata* as a substrate (Figure 2e, f).

The distribution of *Sinotaia quadrata* has expanded in the province of Entre Ríos, along the streams of the Paraná River, which is 280 km away from La Plata and 480 km from Córdoba, highlighting the ability to quickly distribute this species. The aquarium trade has also been proposed as one of the ways of dispersion of this species (Ng et al. 2014), however, the record in the province of Entre Ríos is distant from urban areas, reducing the probability that this has been the way of dispersion. Another possible route could be an intentional introduction for human consumption (Asian communities) (Cianfanelli et al. 2017) or as a food source for carp and related species (Ferreira et al. 2017), however, neither has been confirmed for Argentina. The reproductive and adaptive capacity of *S. quadrata* to different environments, as evidenced in this work and previous works, places this non-native species as a potential invasive species that, in Argentina, will eventually be evident in environmental impacts and effects on society. Ocon et al. (2020) reported that this expansion may lead to competition with native species from the family Ampullariidae, as they share a trophic niche and have been found in the same environment feeding on the same resources. However, Altieri et al. (2022) indicated differential use of food resources between *Sinotaia quadrata* and *Pomacea canaliculata* (Lamarck, 1822) (Ampullariidae). Nevertheless,

these authors emphasize the importance of continuing to monitor interactions with other resources and species and studying potential risks to local fauna.

In North America, a direct competition has been observed between an introduced Viviparidae, *Cipangopaludina chinensis* (Gray, 1833), and native mollusks from the families Physidae Fitzinger, 1833, Lymnaeidae Rafinesque, 1815, and Planorbidae Rafinesque, 1815 (Johnson et al. 2009, Solomon et al. 2010). It is noteworthy that *Sinotaia quadrata* is now recorded in a broader area of the malacological province of the Lower Paraná - Río de la Plata, where 36 species of native freshwater gastropods may be affected by this invasive species, including representatives from the families Lymnaeidae (one sp.), Ampullariidae (eigth spp.), Planorbidae (13 spp.), and Physidae (one sp.) (Núñez et al. 2010). Additionally, in this malacological province, five species are recorded as vulnerable, *Heleobia castellanosae* (Gaillard, 1974), *H. isabelleana* (d'Orbigny, 1835), *Potamolithus agapetus* Pilsbry, 1911, *P. buschii* (Frauenfeld, 1865) and *P. orbignyi* Pilsbry, 1896 (Núñez et al. 2010).

The new environments where the species was discovered differ significantly from those in Córdoba and La Plata. In Córdoba, specimens were found in a river with low flow, featuring riparian and floating vegetation on a sandy or rocky substrate (Ovando & Cuezzo 2012). In contrast, the new record on the Río de la Plata River is on a sandy substrate with continuous water currents affected by tides, exposing individuals during low tides (Figures 2 and 4). These currents can facilitate the dispersion of individuals from the detected site. Additionally, the riparian vegetation, mainly composed of bulrushes (*Schoenoplectus californicus*)

Figure 4. Environments with the new records of *Sinotaia quadrata*. a: Coast of the Río de la Plata River in the Punta Lara Nature Reserve (Ensenada, Buenos Aires); b: Tributary of the Paraná River (Entre Ríos).

(Roesler & Agostini 2012), is very different from the sites in La Plata, characterized by calmer or low-circulation waters and marsh vegetation dominated by water jasmine (*Gymnocoronis spilantoides*), Water Poppy (*Hydrocleys nymphoides*), floating pennywort (*Hydrocotyle ranunculoides*), and Water Primrose (*Ludwigia peploides*) (Ferreira et al. 2017). The site in the province of Entre Ríos is a natural stream with low flow, unaffected by large urban areas, where riparian vegetation, mainly composed of bulrushes (*Schoenoplectus californicus*), just like in RNPL (Figure 4).

Although in the native area *S. quadrata* is a trematode vector, so far records in Argentina have not demonstrated this. The metacercariae of echinostomids can impact humans when consuming undercooked, infested snails (Graczyk & Fried 1998). According to Lu et al. (2018), populations of *S. quadrata* in Japan can also host the parasitic nematode *Angiostrongylus cantonensis* (Chen, 1935), which can cause angiostrongyliasis in humans, damaging the brain and even the lungs, leading to meningitis (Lu et al. 2018). The risk of transmitting possible parasitic diseases using *S. quadrata* as a host in the most populated area of Argentina is therefore significant. In the locality of Punta Lara, in the same location where *S. quadrata* was recorded inhabits, *C. fluminea*, which is collected by individuals from the Asian community for local consumption (Park Ranger pers. commun). We have found an average of 38 ind/m² of this clam in the same quadrants where *S. quadrata* was found, thereby increasing the risk of possible transmission to people.

The high densities and presence of offspring in the brood pouch suggest an adaptation to the new environments, posing a threat to local biodiversity, as has already been observed with other invasive freshwater mollusks in the malacological province of the Lower Paraná - Río de la Plata (Núñez et al. 2010, Darrigran et al. 2020, de Lucía et al. 2023b). Monitoring will continue the coasts of the Río de la Plata, evaluating their parasitological status and with the periodic extraction of specimens with the aim of reducing their density and spread, within the framework of the RNPL management plan.

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Author contributions

DIEGO EDUARDO GUTIÉRREZ GREGORIC and MICAELA DE LUCÍA: conceived the main idea, helped with sampling and data analysis and wrote the manuscript and prepared the figures. SANTIAGO HERNÁN TORRES: wrote the manuscript and prepared the figures. JORGE LUIS ESTEBAN COPA: helped with the review of the drafts and contributed to the discussion of the results. NOELIA C. SÁNCHEZ: helped with sampling and data analysis, wrote the manuscript and prepared the figures. GUSTAVO DARRIGRAN: helped with the review of the drafts and contributed to the discussion of the results.