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The invasive snail *Melanoides tuberculata* (Müller, 1774) (Gastropoda, Thiaridae) in the lower basin of the Sinú River, Córdoba, Colombian Caribbean

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Abstract
We record the invasive thiarid snail *Melanoides tuberculata* (Müller, 1774) for the first time in the lower basin of the Sinú River, Córdoba, Colombia. We counted 2,892 individuals and collected 38 specimens at 4 localities in the basin. The introduction of this species is suspected to have occurred in different ways, but human transport and the aquarium trade are the most probable pathways. The presence of this species in the Sinú River is especially important because of its potential spread to other river basins in the region.

Key words
Invasive species; freshwater molluscs; geographical distribution; regional basins.

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Introduction

The lower basin of the Sinú River in Córdoba, Colombia, is considered a priority area by environmental authorities of the region due to its high productivity and great species richness (CVS 2008, Villadiego et al. 2015). Therefore, it is essential to monitor this wetland, mainly in relation to the introduction of invasive species, as they are considered one of the main causes of biodiversity loss after habitat loss (Vitousek et al. 1996, Leung et al. 2002). The impact of these species on ecosystems causes damage to native species, which can cause a high rate of predation, transmission of diseases and alteration of the structure of trophic levels and their biophysical conditions (Everett 2000, Pino et al. 2010).

Melanoides tuberculata is a highly competitive invasive species and can displace endemic species from the sites where it has been introduced (Fig. 1A); it can also serve as a potential intermediate host of parasites which can affect humans and commercially important fishes (Pointier et al. 1998, Pinto and Melo 2010). This species is native to eastern Africa, eastern Mediterranean, India, southeast Asia, Malaysia, and southern China, and since the 1940s, it has invaded the American continent spreading rapidly throughout the Caribbean (Brown 1994, Rader et al. 2003, Ladd and Rogowski 2012). In Colombia, this gastropod was reported for the first time in the department of Antioquia, at the Joaquín Antonio Uribe Botanical Garden (Areiza et al. 2000, Velásquez et al. 2006, Vergara and Velásquez 2009). There are also records in the department of Huila, in the municipality of Yaguará and in the department of Valle del Cauca, in the municipality of Andalucía (Linares and Vera 2012).

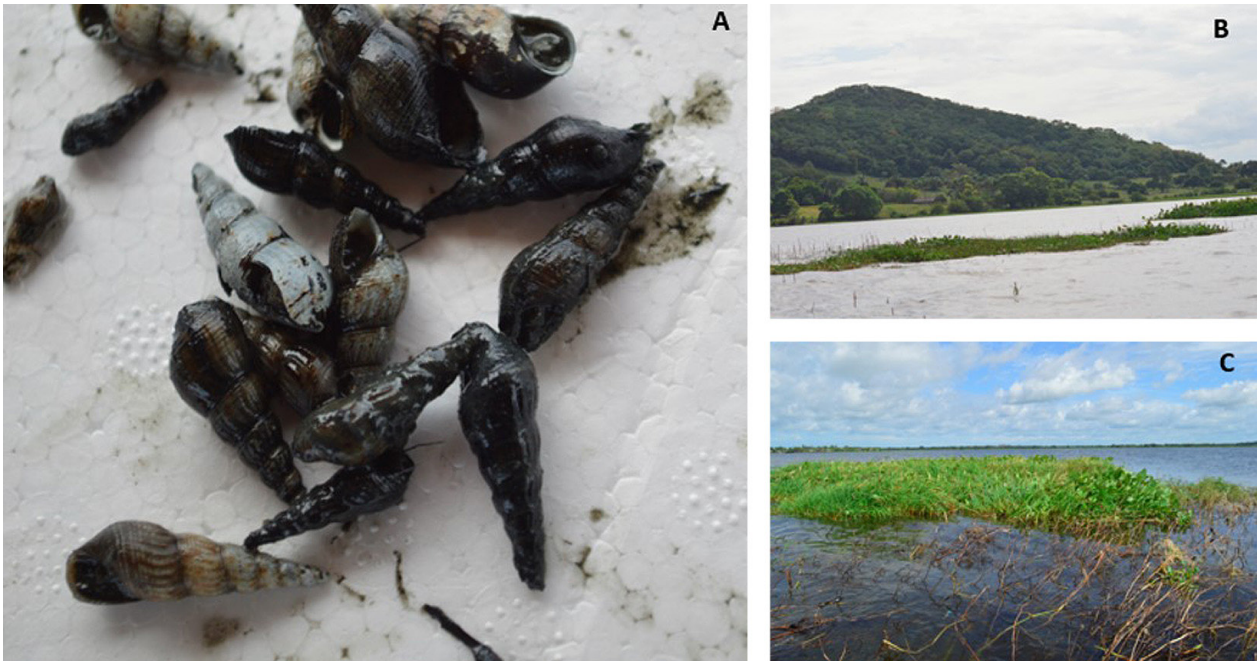

Figure 1. *Melanoides tuberculata* (Müller, 1774). **A.** Aggregate formed by individuals in the lower basin of the Sinú River, Córdoba. **B.** Momil. **C.** Purísima.

The goals of our research are to report the first record of the non-indigenous snail in the Colombian Caribbean, specifically in the lower basin of the Sinú River, to provide a description of its shell to alleviate a lack of previously published information on this species in Colombia, and to highlight the possible dispersal of this invasive species in the basin.

Methods

The lower basin of the Sinú River is a system of interconnected swamps located in the southwest of the Colombian Caribbean coast (Fig. 1B, C). The basin, covering an area of 336.68 km^2, is located in the department of Córdoba. The Sinú River is the main water system in the region; this river fertilizes its valley, which is intensely used for agriculture and livestock. The Sinú River is part of one of the main ecosystems of the Colombian Caribbean coast. Along its course, the river has a complex connections with streams, marshes, and swamps that regulate its level during maximum flood periods (CVS 2009, Montoya and Aguirre 2009, Pérez-Vásquez et al. 2015). We recorded *M. tuberculata* at 4 localities of the basin: Caño de San Vicente, Los Corrales, Momil, and Purísima (Fig. 2). Fieldwork was first carried out at the rainy season in October 2016, and during the dry season in March 2017. In each locality, a line of 30 m perpendicular to the coast was extended, with 3 quadrants of 50 cm × 50 cm placed every 10 m on the line. The specimens collected within the quadrants were stored in plastic bags, labeled, and fixed in 70% ethanol.

Voucher material of *M. tuberculata* was deposited in the Zoology Laboratory of the University of Córdoba (LZUC-MOL). Only individuals collected in each site for shell measurements were deposited as vouchers. Two shell measurements (length and width) were taken in the Microscopy Laboratory of the University of Córdoba, with an HD digital camera attached to the stereomicroscope Axiostar (Zeiss), and then assembled by the image stacking software AxioVision Rel.4.8.2. SP3 (Zeiss).

A 2-way ANOVA was used to test the differences among the average number of snails per locality and sampling season. The values were transformed prior to adding 0.5 to each value then using the square root transformation (Fowler et al. 1998). Post hoc testing was carried out using a Duncan's a posteriori test (Steel and Torrie 1985). All statistics were performed with STATGRAPHICS Centurion program (XV) 16.1.15 (Statpoint 2006). The spatial distribution of *M. tuberculata* was verified for each locality through the index of Morisita (Iδ), with statistical significance verified by F-test (Ludwig and Reynolds 1988), where values of Iδ = 1 indicate random distribution, Iδ > 1 an aggregated distribution and Iδ < 1 a uniform distribution pattern.

Distribution maps were made using QGIS 3.0.2. Longitude and latitude were obtained from the implementation of primary and secondary information. Localities of specimens were plotted on a global land projection using OpenStreetMap (OSM).

Results

Class Gastropoda Cuvier, 1795
Order Caenogastropoda Cox, 1960
Family Thiaridae Gill, 1871 (1823)
Genus *Melanoides* Olivier, 1804

***Melanoides tuberculata* (Müller, 1774)**
Figure 3

Figure 2. Distribution of *Melanoides tuberculata* in Colombia: blue circle = previous records; red circle = new records.

New records. Colombia: Córdoba: Lorica, Caño de San Vicente (09°13′44″ N, 075°48′52″ W, elevation 7 m), Juan Yepes-Escobar, 18-X-2016 (8 individuals, mean shell length = 6.12 mm, mean shell width = 1.78 mm, LZUC-MOL00101); Purísima, Los Corrales (09°13′49″ N, 075°45′29″ W, elevation 7 m), Juan Yepes-Escobar, 21-X-2016 (8 individuals, mean shell length = 10.17 mm, mean shell width = 3.21 mm, LZUC-MOL00102); Purísima, Ciénaga Massi (09°13′26″ N, 075°43′19″ W, elevation 7 m), Juan Yepes-Escobar and Jorge Quirós-

Figure 3. Shells of *Melanoides tuberculata* (Müller, 1774) (LZUC-MOL00104) from the lower basin of the Sinú River, Córdoba, Colombia (scale bar = 1mm).

Rodríguez, 4-III-2017 (12 individuals, mean shell length = 21.23 mm, mean shell width = 6.27 mm, LZUC-MOL00103); Momil, Playón de Momil (09°13′07″ N, 075°40′28″ W, elevation 18 m), Jorge Quirós-Rodríguez, 11-III-2017 (10 individuals, mean shell length = 19.46 mm, mean shell width = 6.13 mm, LZUC-MOL00104).

Previous records in Colombia. Medellín Botanical Garden, Antioquia (Areiza et al. 2000, Velásquez et al. 2006, Vergara and Velásquez 2009), La Tablaza, Antioquia (Escobar et al. 2009), La Ardita, Puente Iglesias, Antioquia (Escobar et al. 2009), Yaguará, Huila (Linares and Vera 2012) and Andalucía, Valle del Cauca (Linares and Vera 2012).

Identification. The conchological characters of the individuals examined agree with the descriptions provided by Samadi et al. (1999: 1146), Facon et al. (2003: fig. 4A), Thompson (2004: fig. 43), and Santos et al. (2012: figs 17A, B, 18).

Description. The shell of *M. tuberculata* is dextral, elongate, with length being greater than twice the width, and sculptured by spiral grooves. Shells of live specimens are predominantly dark brown, with a reddish-brown base. Because of the colour of the base, this species is commonly known as the Red-rimmed Melania (Duggan 2002). The Sinú River basin population has both juvenile and adult individuals. The mean shell length of individuals from the lower basin of the Sinú River was 14.24 mm (N = 38; minimum = 4.82 mm, maximum = 22.49 mm) while the mean shell width of specimens was 4.34 mm (N = 38; min = 1.47 mm, max = 6.83 mm).

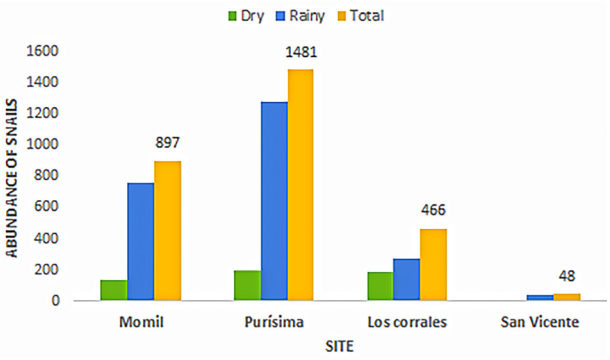

Figure 4. Abundance of snails per site and season in the lower basin of the Sinú River, Córdoba, Colombia: green bar = dry; blue bar = rainy; yellow bar = total.

Population size. We counted the greatest number of individuals in Purísima (1,481 individuals), followed by Momil (897), Los Corrales (466), and San Vicente (48) (Fig. 4). The greatest abundance was recorded in the rainy season (2,358 individuals), while the lowest abundance occurred in the dry season (534 individuals).

Statistically significant differences were established based on the average number of snails, in the study sites (ANOVA; $F = 3.14$, $p = 0.04$) and the months of sampling (ANOVA; $F = 6.96$, $p = 0.01$). Duncan's a posteriori test ($p < 0.05$) showed that mean abundance of *M. tuberculata* at Purisima, Momil and Los Corrales stations was significantly higher than those at San Vicente, which seems to indicate that the population of this snail is segregated by the flow of water and habitat of the lower basin of the Sinú River. By applying the Morisita Index, we found that the values varied between 1.02 in San Vicente and 3.89 in Purísima, revealing the aggregative characteristic of this species.

Discussion

Melanoides tuberculata is an epifaunal gastropod that is dominant on soft mud or sand substrates in shallow slow-flowing bodies of water (Da Silva et al. 1994). It exhibits clear phenotypic plasticity and is reported from a wide range of environmental conditions. It shows high resistance to pollution and other harsh conditions (Pointier et al. 1993, Vogler et al. 2012, Santos et al. 2012). The aquarium trade plays an important role in the dispersal of bioinvaders (Cowie and Robinson 2003, Gutiérrez-Gregoric and Vogler 2010) and was probably the gateway for this gastropod in the Sinú River basin. Several studies emphasize that *M. tuberculata* is capable of displacing native gastropods and even bivalves (Hershler 1998, Rader et al. 2003, Peso et al. 2010). Roessler et al. (1977) found that the growth and reproduction of *Neritina virginea* (Linnaeus, 1758) declined

in the presence of *M. tuberculata*, presumably because of resource competition.

In contrast to Purísima and Momil, we found the abundance of *M. tuberculata* to be very low at San Vicente; the populations are not found permanently established here and are probably brought down to this area by the currents during the rainy season. The ability of *M. tuberculata* to resist displacement by rapid currents has not been measured. However, Pointier et al. (1994) found that this snail is uncommon in fast-flowing rivers in Venezuela. Other authors have observed that *M. tuberculata* can reach high densities in ponds and gently flowing waters (Miyahira et al. 2009). Although this species was abundant in a swiftly flowing canal in Louisiana, it primarily occurred in macrophyte beds where current was reduced (Dundee and Paine 1977). High abundances and in particular the environmental tolerance of adults (Pereda et al. 1990, Burlakova et al. 2010) can ensure the persistence of *M. tuberculata* in the basin. It is suggested that the mode of reproduction and the type of embryo development, which possibly play a very significant role in the spread and establishment of this species, would also affect its population dynamics (Ben-Ami and Hodgson 2005, Miranda et al. 2011). The clustered distribution of *M. tuberculata* was maintained in the 2 periods of the year with similar Iδ values, which shows that seasonality does not affect the spatial distribution pattern for this species, which is comparable to other studies (Iannacone et al. 2003, Albarrán-Melze et al. 2009).

We recommend that the monitoring and control of *M. tuberculata* in the basin of the Sinú River, to assess this species' potential for establishing populations and the associated consequences of its presence on the river system. An understanding of the population dynamics of this species is important for predicting its interaction with the environment and determining the best control strategy (Burlakova et al. 2010). Habitats that have already been invaded by *M. tuberculata* present opportunities to learn how *M. tuberculata* interact with the environment (Miranda et al. 2011). Likewise, ecological studies are necessary to understand the invasive behavior and impacts of this species in newly invaded areas of Colombia.

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Authors' Contribution

All authors contributed to the drafting and editing of the manuscript. JQ and JY participated in the data collection. JQ and GS identified the species.

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