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Rapid Communication

# New records of invasive mollusks *Corbicula fluminea* (Müller, 1774), *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1816) in the Vicente Guerrero reservoir (NE Mexico)

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## Abstract

The Vicente Guerrero reservoir is the sixth largest water reservoir in Mexico. This is a primary water source for the northeast region as well as a frequently holiday touristic site. In this paper we report aquatic specimens of the bivalve *Corbicula fluminea,* along with the gastropods *Melanoides tuberculata* and *Tarebia granifera* for the first time in the reservoir. This is also the first report of *M. tuberculata* and *T. granifera* for the Soto la Marina basin, and the first record of *T. granifera* for Northeast Mexico. The establishment of these species in the water body represents a potential threat to the native species and human health, since they are intermediate hosts in the life cycle of some parasites, such as *Centrocestus formosanus* trematode. Their arrival may be due to aerial, aquatic or commercial dispersion, since they can become adhered to, and hidden easily on birds, boats or aquarium ornamental plants, respectively. The introduction of these species may also cause potential economic losses for the agricultural, aquaculture and fishing activities in the local area. Due to high potential of dispersion, displacement of native species and pathogen transmission, the establishment of preventive actions is recommended to avoid their potential expansion in other aquatic bodies of the Soto la Marina basin.

**Key words:** Asian clam, introduced gastropods, aquatic species, Soto la Marina basin, parasitic hosts

## Introduction

The dispersion of invasive species is one of the main reasons of biodiversity loss, which is a cause of great concern worldwide due to the harmful effects on the ecosystem, as well as on the economy and the human health (Mooney and Cleland 2001; Stohlgren and Schnase 2006). Despite the aquatic invasive species involve economic impacts on agricultural, fishing and international commercial activities (Lovell et al. 2006), in Mexico, there are few regulations to prevent and control the introduction pathways of aquatic non-indigenous species (Okolodkov et al. 2007). According to the last authors, the incrustations on hulls as well as the aquaculture activities and ballast water seem to be the main causes for its introduction, in percentages that vary from 25 to 36%.

One of the most invasive mollusks of greatest importance in freshwater aquatic ecosystems is the Asian clam *Corbicula fluminea* (Müller, 1774), since due to its biological traits can easily colonize new environments (Araujo et al. 1993; Sousa et al. 2008; Ferreira-Rodríguez et al. 2018). In North America, the first collection of Asian clams, was reported in the northeastern Pacific Island of Vancouver (Canada), in 1924 (Counts 1981); since then, *C. fluminea* has become widespread in the United States (Britton and Morton 1979). In Mexico, it was first registered in Baja California and Sinaloa (northwestern states, Pacific Ocean coast), in 1970 (Fox 1970); then, it was detected in Tamaulipas (northeastern state, Gulf of Mexico Coast), since 1981 and until 1984 (Hillis and Mayden 1985). A quarter century later, in 1995, it was recorded in Chiapas, Colima, Jalisco, Nayarit, and Sonora (western states) as well as in Chihuahua, Durango, San Luis Potosí and Zacatecas (north-central states) and Veracruz (eastern state) (Contreras-Arquieta et al. 1995; Torres-Orozco and Revueltas-Valle 1996; Contreras-Arquieta and Contreras-Balderas 1999; Barba-Macías and Trinidad-Ocaña 2017).

Another of the most invasive mollusks of worldwide concern are the gastropods *Melanoides tuberculata* (Müller, 1774) and *Tarebia granifera* (Lamarck, 1816); these species are commonly known as "red-rim melania" and "quitted melania", respectively. These species, similar in size and morphological features between themselves, are native from the southern Asian region, although *M. tuberculata* is natural also from the African subtropical and tropical areas (Abbott 1952). In North America, the two species were introduced in Florida (United States), in 1935 and 1949, separately (Abbott 1952; Roessler et al. 1977). For Mexico, the first records of *M. tuberculata* were in the states of Coahuila, in 1966, and Veracruz, in 1973 (Taylor 1966; Abbott 1973); while for the case of *T. granifera*, the first register occurred in Chiapas, in 1995 (Contreras-Arquieta et al. 1995). Since then, these species have been studied in other regions of Mexico, such as in rivers and lakes of the east and south regions, in Veracruz and Tabasco (López-López et al. 2009; Rangel-Ruiz et al. 2011; Barba-Macías et al. 2014), among others.

Despite the wide geographic dispersion of invasive bivalves and gastropods, there is currently a lack of knowledge about their distribution in most of the aquatic bodies of Northeast Mexico. Particularly, the Vicente Guerrero reservoir has characteristics that may favor colonization

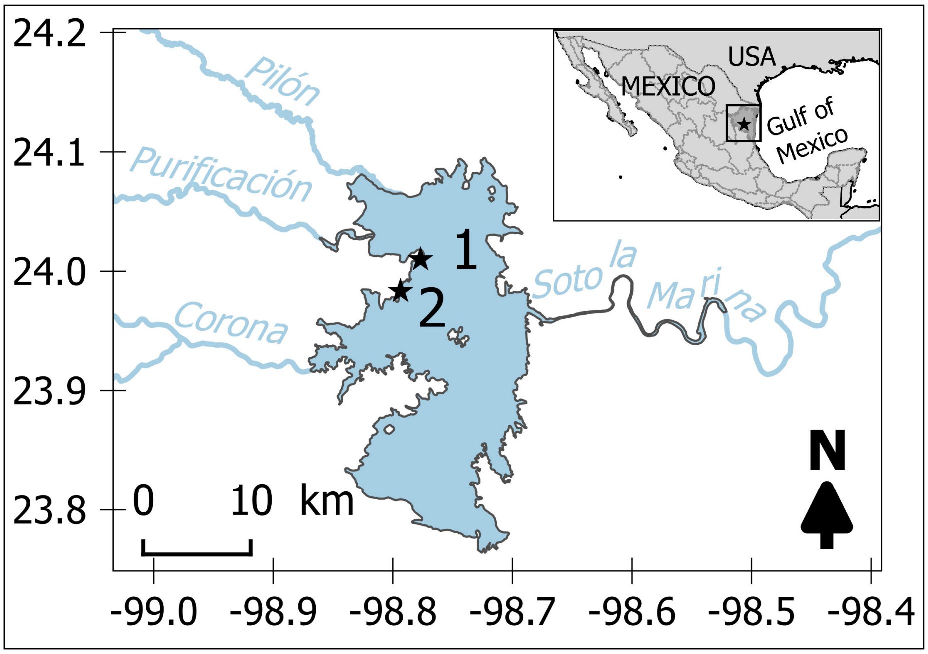


**Figure 1.** Vicente Guerrero reservoir and location of sampling sites (1 and 2) of the current study in 2018. Inset map: Mexico hydrological regions (HR); San Fernando-Soto la Marina HR is shaded in dark grey.

by invasive mollusks, since these species prefer lake and water reservoirs (Karatayev et al. 2018). The aim of this work is to expand the knowledge of the distribution of invasive mollusks and confirm the first records of the Asian clam (*C. fluminea*) along with the gastropods *M. tuberculata* and *T. granifera* in the Vicente Guerrero reservoir, located in Northeast Mexico.

## Materials and methods

### *Study area*

The Vicente Guerrero reservoir (VGR), commonly known as "Las Adjuntas" is located in the municipality of Padilla (state of Tamaulipas) and is the sixth largest reservoir in Mexico, with a water capacity of 3833 $hm^3$ (CONAGUA 2018). In terms of its hydrography, receives water from the Pilón, Purificación and Corona rivers (Figure 1); these rivers come from the municipalities of Hidalgo, Padilla and Victoria, respectively. At the same time, the reservoir flows into the río Soto la Marina, which in turn flows into the Gulf of Mexico. The VGR is an important fishing area for human consumption, especially catfish *Ictalurus punctatus* (Rafinesque, 1918), common carp *Cyprinus carpio* (Linnaeus, 1758) and blue tilapia *Oreochromis aureus* (Steindachner, 1864) (Elizondo-Garza et al. 1996; Uresti-Marín et al. 2008); there are also catches of largemouth bass *Micropterus salmoides* (Lacépède, 1802), alligator gar *Atractosteus spatula* (Lacépède, 1803) and Texas cichlid *Herichthys cyanoguttatus* (Baird and Girard, 1854), the latter two in smaller numbers (Elizondo-Garza et al. 1996).

The reservoir has undergone some anthropogenic pressure, including the presence of organochlorine pesticides in carp and bass, due to agricultural


**Figure 2.** Collected specimens of Asian clam in Vicente Guerrero reservoir. Photographs by Alfonso González Juárez.

and livestock activities in the area (Uresti-Marín et al. 2008). In addition, potentially zoonotic larvae from the parasitic helminth *Contracaecum* sp. have been detected in the introduced species *C. carpio* and *M. salmoides* (Garrido-Olvera et al. 2017). As well as pollution, invasive species may also pose a potential threat to the survival of native fish species (Karatayev et al. 2009).

*Sampling, identification and registration*

A total of 50 specimens of mollusks were collected in March 2018 on the shores of the northwest area of the Vicente Guerrero reservoir (Figure 1). In this area, samplings were taken in ten quadrats of 1 $m^2$, distributed along two transects of 1 × 100 m, parallel to the shore. The two transects had a separation of 2000 meters, with the specimens collected in two different types of substrates: rocky and sandy. The type of sampling for the selection of the organisms carried out was of convenience, so that only specimens of *C. fluminea* (Figure 2), *M. tuberculata* and *T. granifera* (Figure 3) were collected. Organisms from other mollusks species, occasionally observed, were discarded. In each transect, the collected individuals were counted to obtain densities (individuals/$m^2$). All samples were collected manually, fixed in 4% formaldehyde and transported to the zoology laboratory of the Institute of Applied Ecology for identification. The collected specimens of each of the species were identified through taxonomic keys (Thompson 2004; Todd et al. 2008; Isnaningsih et al. 2018; Mollusca Base 2018). Also, these organisms were measured (length, width and whorls). Finally, the samples were conserved in 70% ethanol and some specimens were deposited in the National Collection of Mollusks (CNMO), Institute of Biology, National Autonomous University of Mexico, with access numbers 7588, 7589 and 7590.

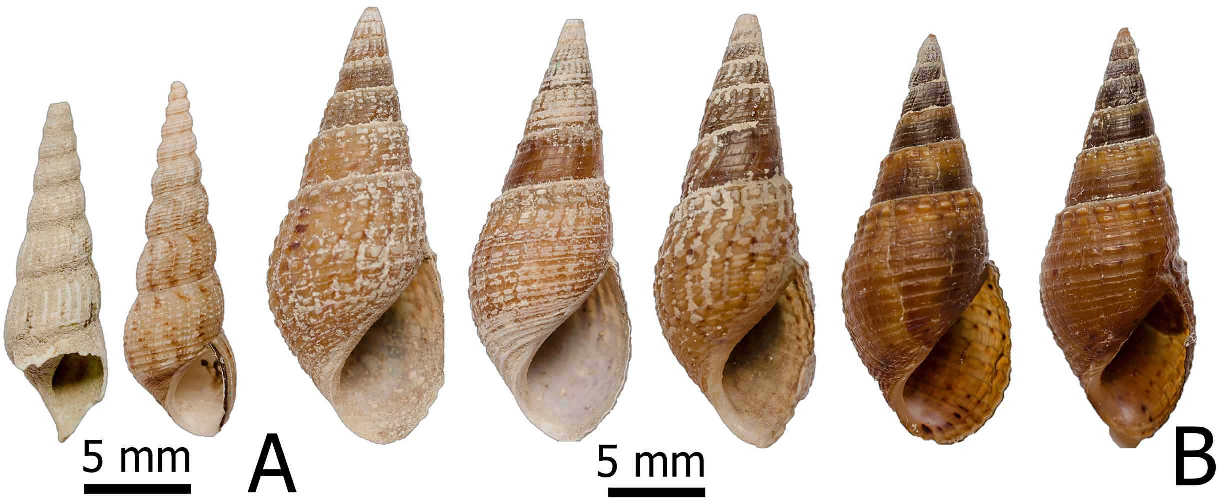


**Figure 3.** Collected organisms of gastropods in Vicente Guerrero reservoir. Letters: (A) *Melanoides tuberculata;* (B) *Tarebia granifera.* Photographs by Alfonso González Juárez.

**Table 1.** Length, width and whorls range (mean ± Standard Deviation) in *Corbicula fluminea*, *Melanoides tuberculata* and *Tarebia granifera* specimens, collected in Vicente Guerrero reservoir. Abbreviations: n = number of organisms; NA = not applicable.

| Species | Total length (mm) | Total width (mm) | Whorls (units) |
|---|---|---|---|
| *C. fluminea* (n = 24) | 9–24 (19.9 ± 2.30) | NA | NA |
| *M. tuberculata* (n =4) | 14–18 (16 ± 2) | 5–6 (5 ± 0.81) | 6–8 (7.5 ± 1) |
| *T. granifera* (n = 22) | 2–20 (13.82 ± 6.13) | 1–9 (5.45 ± 2.38) | 3–5 (4 ± 0.5) |

### *Literature revision and species distribution map*

To show the relevance of the findings of the three species in their known distribution from North America to Central America, we conducted a literature revision reporting their presence independently of the study topic. The revision of the registers in North America was made through the Nonindigenous Aquatic Species Database of the US Geological Survey (Benson 2019; Daniel et al. 2019; Foster et al. 2019). For Mexico and Central America, the revision of the species registers was made through a web-search in databases, using the names of species and countries for North and Central America, as keywords. After the revision, the registers were included in a excel file, which was processed to develop the species distribution maps, through the Version 2.18.24 of QGIS software© (QGIS Development Team 2018).

## Results

### *Main features of the species collected*

A total of 24 specimens of Asian clam (*C. fluminea*), 4 of *M. tuberculata* and 22 of *T. granifera* were collected from the Vicente Guerrero reservoir. All individuals collected were found above the sediment surface, submerged in water at a depth between one and 30 cm. Their length, width, as well as whorls number are summarized in Table 1 (for details see Supplementary material Table S1). Most of the organisms collected were of adult size, but there were also some newly formed individuals of *T. granifera*.

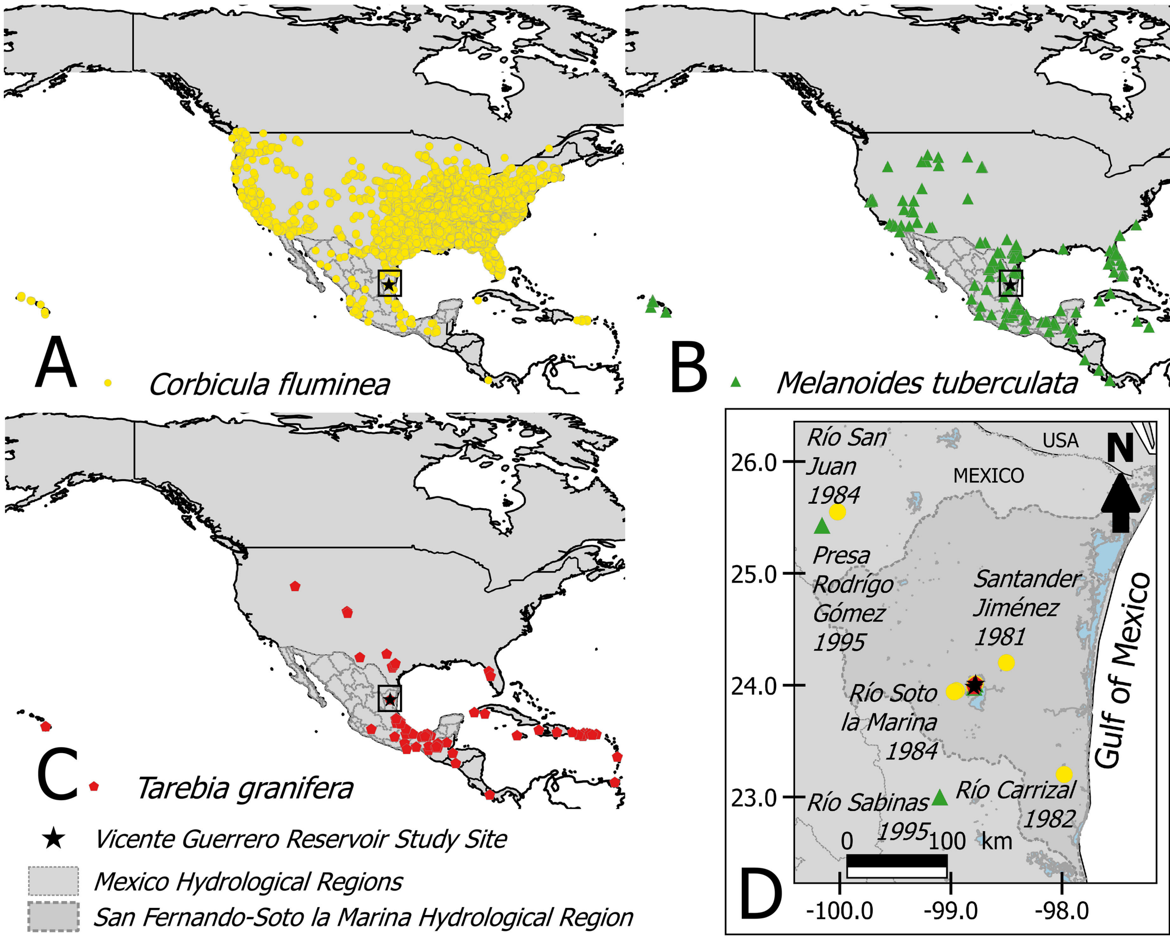


**Figure 4.** North and Central America distribution map of *Corbicula fluminea* (A), *Melanoides tuberculata* (B) and *Tarebia granifera* (C), with the San Fernando and Soto la Marina basins, sites and years when each species was first detected near to the Vicente Guerrero reservoir study site (D). Data sources and references are provided in Tables S2 to S3.

*Description of habitat*

The organisms of the mollusk species mentioned above were found in both transects; however, a larger number of gastropods was observed in the first transect, where high numbers of *T. granifera* (density > 50 individuals/m$^2$) were observed in shallow waters (< 0.1 m) adhering to the substrate formed by rocks and other construction materials. *M. tuberculata* was also present in this same transect, although with lower abundance (density < 5 individuals/m$^2$). The transect exhibited the presence of filamentous green algae and a slight current of water that was reduced by the abandoned building blocks. On the other hand, the second transect showed a greater abundance of *C. fluminea* (density > 100 individuals/m$^2$), as well as a slight presence of filamentous green macroalgae.

*Known distribution*

After the first reports of *Corbicula fluminea* mentioned above in North America, it has been established in 48 states of the United States, except for Alaska and North Dakota, representing the 96% of the US states, without the District of Columbia, where was also registered (see Figure 4 and Table S2).

In Mexico, this species has been registered in all the states from the Pacific Ocean side (from Baja California to Chiapas, excepting Guerrero); on the north and central-north regions it has been recorded in all the states, excepting Aguascalientes, Querétaro and Guanajuato. Finally, for the northeastern, eastern and southern regions, it has only been recorded in Tamaulipas, Veracruz, Oaxaca, Chiapas and Tabasco; counting the Mexican states where this species has been registered, it represents an 53% approximately. Moreover, in Central America and Caribbean countries, it has been detected in a lesser extent, in Cuba, Panama and Puerto Rico (see Figure 4 and Table S3).

Concerning to the distribution of the gastropods *Melanoides tuberculata* and *Tarebia granifera* have been reported from several western, central and southern states of United States, representing the 34% and 5% of the US states without Hawaii and Puerto Rico, respectively (see Figure 4 and Table S2). In Mexico, *M. tuberculata* has been detected in the states from the Pacific Ocean side (from Baja California to Chiapas, excepting Sinaloa, Sonora and Oaxaca); on the north and central region it has been registered in the states of Zacatecas, San Luis Potosí, Morelos, as well as in the northeast, east and southeast regions excepting Tamaulipas, Hidalgo and Yucatán, respectively. While for *Tarebia granifera*, in Mexico it has been detected in Michoacán and Oaxaca (western states) as well as in Veracruz, Tabasco and Campeche (eastern and southern states). Although both species are becoming widespread, less records were reported for *T. granifera* compared to *M. tuberculata* (representing only a 18.7% *vs* 65% of the Mexican states, respectively). Otherwise in Central America *M. tuberculata* and *T. granifera* were reported in all countries (excepting Guatemala and El Salvador in the first case, as well as Nicaragua, El Salvador and Costa Rica for the second); furthermore, both species were detected in most of the Caribbean islands (see Figure 4 and Table S3).

## Discussion

### *Registration of the species*

Currently, there are 56 introduced species of mollusks that have been registered in Mexico; within freshwater mollusks, the dominant group is gastropods, in particular the families Ampullariidae, Thiaridae and Planorbidae (Naranjo-García and Castillo-Rodríguez 2017). The bivalves of the family Cyrenidae (*C. fluminea*), together with the gastropods of the family Thiaridae (*T. granifera* and *M. tuberculata*) are invasive species in Mexico (Thompson 2011; CONABIO 2017a, b, c). In Tamaulipas, *C. fluminea* was registered in Santander Jiménez, río Carrizal and río Soto la Marina (1981, 1982 and 1984, respectively), bellonging to the Soto la Marina basin; another register was in the río San Juan (1984) occurred within the río Bravo basin (Hillis and Mayden 1985). Otherwise and about ten years later, *M. tuberculata* was detected in the Presa Rodrigo Gómez in 1995 and the río Sabinas in 1995 bellonging to the río Bravo and río Tamesí basins, respectively (Contreras-Arquieta et al. 1995; Albarrán-Melze et al. 2009). In a contrary way, *T. granifera* has not been previously registered in any of the northeast basins of Mexico. Then, this work represents the first record of *C. fluminea*, *M. tuberculata* and *T. granifera* in the Vicente Guerrero reservoir (NE Mexico), the first record of *M. tuberculata* and *T. granifera* for the Soto la Marina basin and the first one of *T. granifera* for Northeast Mexico. It is also important to recognize that although the species of *C. fluminea* and *M. tuberculata* have been recorded in Tamaulipas (Hillis and Maiden 1985; Contreras-Arquieta et al. 1995), there is still a lack of knowledge about their distribution in most of the aquatic bodies.

*Probably causes of its introduction*

This reservoir, located in the middle of the state, is a refuge for migratory birds, which may disseminate these mollusk species to other bodies of water, through excretion pathway. Experimentally, it has been shown that birds can carry and introduce snails to different locations, while egg masses or snails can be moved by mud or vegetation attached to mammals (Derraik 2008). Although the exact causes for their presence in this waterbody are still unclear, seems unlikely that was occurred by hydrological reasons, because the rivers draining to VGR (Pilón, Purificación and Corona), into Soto la Marina basin, are not connected with their neighboring basins (río San Fernando and río Tamesí). According to Hillis and Maiden (1985) this reservoir is frequently visited by fishermen from the United States and suggested that the *Corbicula* detected in the río Soto la Marina, in 1984, was due to the passively introduction in the VGR. Therefore, is likely that the three species currently reported in the reservoir were accidentally introduced by the fishing tourism as well as the arriving boats for sports or fishing for human consumption; these boats come from several bodies of fresh and saltwater from all over Mexico, as well as other regions and may carry the mollusks attached to the hull, with the consequent introduction and dispersion when they reach a new waterbody. Furthermore, domestic aquaria are another source for the introduction of mollusks in new habitats, since these species are often found attached to the aquatic plants sold in the aquarium stores (Rangel-Ruiz et al. 2011). Water discharge from these mollusk-contaminated aquaria into the municipal sewage system allows for their dispersion to new bodies of water. CONABIO (2018) has listed a number of actions that are recommended to prevent the spread of these invasive alien species, which include avoiding the emptying the fish tank contents (fish, plants, gravel, etc.) into rivers, lagoons and canals or municipal drainage, especially if the origin of the pets cannot be confirmed; to keep field equipment and vehicles clean; to avoid moving earth from one place to another and finally, to avoid bringing animals or plants from other places as a souvenir.

*Habitat conditions*

The finding of *C. fluminea* specimens on sandy, silty and rocky substrates agrees with that reported by Barba-Macías and Trinidad-Ocaña (2017); these authors found that *C. fluminea* best habitat corresponds to flat areas with a different variety of substrates (rocky, sandy and silty bottoms, with organic matter and floating vegetation) and in shallow areas with a higher concentration of suspended materials. This coincides with the present study, since the studied zone corresponded to one of the ends of the reservoir where hydrographic conditions of the water flow receive suspended particles.

*Potential impacts derived of its introduction*

The introduction of these species in the VGR is worrying because *C. fluminea* poses a threat to the hydraulic infrastructure, causing damage to irrigation channels and drinking water pipes (Paunović et al. 2007), apart from the displacement of native species (Sousa et al. 2008). Due to the potential impact of *C. fluminea*, derived from its establishment and expansion, its presence can lead to economic losses for agricultural activities due to the clogging of irrigation systems caused by this species (McMahon 1983). Regarding *M. tuberculata* and *T. granifera,* it has also been found that these species serve as intermediate hosts in the life cycle of parasites such as *Paragonimus kellicotti* (Ward, 1908), *Clonorchis sinensis* (Looss, 1907) or *Centrocestus formosanus* (Nishigori, 1924) (Goldsmith and Heyneman 1995; Cowie and Robinson 2003; Facon et al. 2003; Derraik 2008). Particularly, *M. tuberculata* is considered to be of medical significance in New Zealand, because most of the fourteen species of parasitic trematodes reported by Derraik (2008) can affect human health. Specifically, in Mexico the transmission of the *C. formosanus* trematode from the mollusk *M. tuberculata* to natural populations of the fish *Xiphophorus hellerii* (Heckel, 1848) and *Gobiomorus dormitor* (Lacèpede, 1800) has been detected (Salgado-Maldonado et al. 1995); thus, the introduction of trematodes through *M. tuberculata* could have negative consequences in local communities, intermediate hosts (aquatic snails, fish), as well as native aquatic birds and occasionally mammals that act as definitive hosts (Mitchell et al. 2005; Pinto and Melo 2011). As in *M. tuberculata*, the *T. granifera* species has been registered as an intermediate host of cercaria species of the genus *Haplorchis*, a zoonotic parasite in Southeast Asia (Ditrich et al. 1990; Giboda et al. 1991; Appleton et al. 2009). According to Giboda et al. (1991), these infections were transmitted due to the population's habit of consuming raw fish, beef and pork. It should be mentioned that in some areas of South Africa, the rapid dispersion and population density reached by *T. granifera*, could increase the frequency of infections in humans (Appleton et al. 2009).

The presence of these three species may have potential ecological impacts in this reservoir, just as it has been reported in other waterbodies. One of the impacts caused by *C. fluminea* may be the replacement of native forms rapidly (Sousa et al. 2008). According to these authors, *Corbicula* species potentially affect the displacement and/or reduction of available habitats for juvenile unionids and sphareiids natives, due to the burrowing and bioturbation activity (Vaughn and Hakenkamp 2001). For gastropod's species, anecdotal reports and observations suggest that in KwaZulu-Natal the indigenous *M. tuberculata* has becoming less common because of the high densities reached by *T. granifera* (Appleton et al. 2009). According to the last authors, *T. granifera* becomes numerically dominant from several habitats where *M. tuberculata* and *T. granifera* occur sympatric. Also, *M. tuberculata*, can also be a host for fish-invading trematodes and affect wild fish as well as native ichthyophages birds (Karatayev et al. 2009).

Finally, further studies on the distribution of these species in the VGR are recommended, as well as in the bodies of water surrounding the Soto la Marina basin, which flow into the reservoir and then to the Gulf of Mexico, for timely detection and possible future control actions.

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**Supplementary material**

The following supplementary material is available for this article:

**Table S1.** Details of *Corbicula fluminea*, *Melanoides tuberculata* and *Tarebia granifera* collected in March 2018 in the Vicente Guerrero reservoir.

**Table S2.** Details of *Corbicula fluminea*, *Melanoides tuberculata* and *Tarebia granifera* registered in the United States. Source of data: Daniel et al. (2019), Foster et al. (2019) and Benson (2019).

**Table S3.** Details of *Corbicula fluminea*, *Melanoides tuberculata* and *Tarebia granifera* in Central America, the Caribbean and Mexico and data sources. Complete references are provided at the end of the records included on the table.