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*Corbicula fluminea (*Bivalvia: Corbiculidae), the great invader of Gatun Lake, Panama.

Corbicula fluminea (Bivalvia: Corbiculidae), el gran invasor del lago Gatún, Panamá.

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Abstract

In order to recognize clam species that pose a threat to the freshwater extraction tunnels of the Panama Canal locks, specimens were collected, which were obtained by diving from the shore at a depth of three meters, every month throughout the year 2025, on the shores of Gatun Lake, in the sector of the town of La Arenosa. district of Chorrera. Panama West Province, Panama, between the approximate coordinates 9°12′N 79°54′W; all specimens were packaged in airtight plastic bags that were placed in a refrigerated container for transport to the facilities of the Museum of Malacology of the University of Panama (MUMAUP), where they were identified and labeled. The 2500 specimens were identified as *C. fluminea* (Asian clam), had a hard, rounded and triangular shell, with very marked concentric striations, glossy periostracium (brown, green or yellowish) and a pearly interior ranging from white to purple, with three cardinal teeth and denticulated laterals. The presence of this clam in Gatun Lake, Panama, is a problem because it obstructs the hydraulic infrastructures of the Panama Canal, such as pipes and filters, competes for food and resources with native species; These bivalves filter water, reproduce quickly, and were likely introduced by ships' ballast water. In addition, this species is a classic example of an exotic invasive species that has successfully colonized freshwater bodies on almost every continent, generating environmental and economic challenges.

Keywords: alien species, clam**,** interoceanic channel, invasive

Resumen

Con el fin de reconocer especies de almejas que representan una amenaza para los túneles de extracción de agua dulce de las esclusas del Canal de Panamá, se recolectaron ejemplares, que se obtuvieron buceando desde la orilla a tres metros de profundidad, cada mes durante todo el año 2025, en las orillas del lago

Gatún, en el sector de la localidad de La Arenosa, distrito de Chorrera. Provincia de Panamá Oeste, Panamá, entre las coordenadas aproximadas 9°12′N 79°54′O; todos los especímenes se empaquetaron en bolsas de plástico herméticas que se colocaban en un contenedor refrigerado para su transporte a las instalaciones del Museo de Malacología de la Universidad de Panamá (MUMAUP), donde eran identificados y etiquetados. Los 2500 ejemplares fueron identificados como *C. fluminea* (almeja asiática), tenían una concha dura, redondeada y triangular, con estrías concéntricas muy marcadas, periostrácio brillante (marrón, verde o amarillento) y un interior perlado que iba del blanco a púrpura, con tres dientes cardinales y laterales denticulados. La presencia de esta almeja en el lago Gatún, Panamá, es un problema porque obstruye las infraestructuras hidráulicas del Canal de Panamá, como tuberías y filtros, compite por alimento y recursos con especies autóctonas; estos bivalvos filtran el agua, se reproducen rápidamente y probablemente fueron introducidos por el agua de lastre de los barcos. Además, esta especie es un ejemplo clásico de una especie invasora exótica que ha colonizado con éxito cuerpos de agua dulce en casi todos los continentes, generando desafíos medioambientales y económicos.

Palabras clave: almeja, canal interoceánico, especies exótica, invasora

Introduction

Biological invasions of non-native species often occur due to human intervention and represent one of the biological/ecological alterations that occur on a global scale as a result of globalization (e.g., Crespo *et al*., 2015). In the context of current global changes, biological invasions emerge as an event in themselves (Simberloff *et al*., 2013). Transitional ecosystems, particularly estuaries, are highly susceptible to biological invasion events, as various human activities that are important vectors of introduction are concentrated in these areas (e.g., fisheries, ballast water, general human occupation, aquaculture) (Cohen & Carlton, 1998; Williams & Grosholz, 2008). Known as fundamental biological areas, estuaries are highly productive habitats (Kennish, 2002; Dolbeth *et al*., 2011; Hicks *et al*., 2011) and functionally important (e.g., Sousa *et al*., 2010 and 2012).

Since estuaries are generally characterized by low diversity due to particular physicochemical conditions (Loo & Rosenberg, 1996; Kennish, 2002; Dolbeth *et al*., 2011; Hicks *et al*., 2011), the introduction of new species with high potential for expansion and competition could have a disproportionate effect on ecosystem functioning (Stachowicz & Byrnes, 2006; Sousa *et al*., 2008b). The Asian clam, *Corbicula fluminea* (Müller, 1774), is among the most invasive species in freshwater systems (McMahon, 2002; DAISIE, 2008; Sousa *et al*., 2008a), with a wide global distribution and high invasive efficiency (Crespo

et al., 2015). This species can affect hydrology, biogeochemical cycle, and biotic interactions through two general mechanisms: assimilation-dissimilation processes (absorption and release of energy and materials) and physical engineering of the ecosystem (physical modification of the environment by organisms), with impacts ranging from individuals to ecosystems (Hakenkamp *et al.*, 2001; Sousa *et al*., 2009; Atkinson *et al*., 2011). This species can create a different habitat matrix for benthic fauna through bioturbation and shell production (Ilarri *et al*., 2012 and 2014) and has high filtration rates, which reduces the availability of phytoplankton for other species (Foe & Knight, 1985; Phelps, 1994; Hakenkamp *et al*., 2001; Sousa *et al*., 2008a). It is a highly productive bivalve, which can cause disruptions in the food chain, either as a consumer or as a food source for higher trophic levels, especially when mass die-offs occur (McMahon, 2002; Sousa *et al*., 2008b and 2012b).

Despite being a freshwater species, *C. fluminea* can tolerate salinities of up to 10-14 (in LMUs, without units) (McMahon, 1983 and 1999), allowing it to colonize areas upstream of estuaries (Sousa *et al*., 2008b; Franco *et al*., 2012; Ilarri *et al*., 2014). Its life cycle favors the ability to invade other systems, due to its rapid growth rates, early maturation (McMahon, 1999 and 2002; Sousa *et al*., 2008a) and its capacity for androgenesis and self-fertilization (Pigneur *et al*., 2011). Juveniles are released as pediveligers, and their dispersal is facilitated by a mucilaginous drift line (Prezant and Chalermwat, 1984; Rosa *et al*., 2012). In addition, the species is known to possess great phenotypic plasticity, indicated by a wide range of shell and body mass characteristics for geographically close systems (Sousa *et al*., 2007; Vohmann *et al*., 2010; Rosa *et al*., 2012), which is another feature that contributes to its invasive potential. Awareness of the impact of the species has been increasing, as it has generated significant economic impacts in North America due to biofouling (Mattice, 1977; Rosa *et al*., 2011). The species has been present in North America since the mid-1930s, in South America since the 1960s (Darrigran, 2002), and in Europe since the 1980s (Ilarri & Sousa, 2012; Crespo *et al*., 2015).

Despite the wide availability of information on its vital limits, genetics, physiology and metabolism, there is still an information gap on how the species can cope with adverse cyclical conditions such as those found in estuaries. Physicochemical parameters (e.g., salinity, temperature, water depth, turbidity) change according to cycles of different durations (McLusky, 1993; Teixeira *et al*., 2008; Pratt *et al*., 2014) in estuaries, so it is important to assess whether C. *fluminea* populations can thrive in such unstable environments. In addition, as transitional habitats, estuaries exhibit complex gradients (e.g., in a neotropical reservoir; Paschoal *et al*., 2015), with horizontal, vertical, cross-sectional, or other patterns, in relation to the aforementioned abiotic factors (McLusky, 1993). As an invasive species responsible for high levels of

Vol. 6 (2) abril – septiembre 2026, pp. 101-114, ISSN-L 2710-7469

secondary production (Phelps, 1994; McMahon, 2002; Sousa *et al*., 2008b), could harness much of the energy available in estuaries (Vannote *et al*., 1980). This could pose an additional threat to native biodiversity, with disruptive effects on the functions and processes of native organisms.

C. *fluminea* (Asian clam) is present and abundant in Gatun Lake and the Panama Canal, being an introduced species that is part of the food base of local aquatic ecosystems and has been the subject of scientific studies for its role in food webs and its potential impact, with reports since 1990 in the Santa María River (Veraguas) and studies confirming its presence in the Gatun Locks and in samples from the lake between 2013-2018, probably introduced by ballast water or as a larva in farmed fish such as carp and tilapia, and is considered an invasive species that can cause negative impacts on water systems, affecting ecology and potentially hydraulic infrastructure.

This article presents the results of a field experiment in which invasive species was first located. *C. fluminea* in the town of La Arenosa, Chorrera, on the slopes of Gatun Lake, the main freshwater tributary of the Panama Canal. This will allow us to predict whether the species poses a threat to the Panama Canal locks' freshwater extraction tunnels and whether it is sufficient to prevent further advance.

Material and methods

Location of the study area: The town of La Arenosa is in the township of Mateo Iturralde in the district of La Chorrera, Panama, and is famous for being on the shores of Gatun Lake, being a popular destination for fishing, water activities and enjoying nature, with piers and lodging options nearby, offering a rural escape close to the city.

Field methodology: The sampling was carried out by diving up to three meters deep from the shores of Gatun Lake in the sector of the town of La Arenosa, district of Chorrera, province of Panama Oeste, Panama; every month throughout the year 2025, from January to December, collecting specimens of bivalves manually diving at depths of up to three meters on the shores of Gatun Lake in the sector of the town of La Arenosa, district of Chorrera, province of Panama Oeste, Panama, between the approximate coordinates of 9°12′N 79°54′W; all specimens were packed in airtight plastic bags that were placed in a refrigerated container for transport to the facilities of the Museum of Malacology of the University of Panama (MUMAUP).

Laboratory Methodology: After sampling, the biological material was taken to the MUMAUP, for identification. Prior to identification, the specimens had their soft-shell body removed; then they were

placed in the oven. For identification, the morphological characteristics of the shell were taken into account, such as its opening, the siphonal canal and the muscular footprint of the bivalve. They were then taxonomically located with the help of the Bivalve Seashells of Tropical West America (Coan & Paul Valentic-Scott 2012), exclusive to Pelecypoda and the taxonomic update was verified on the World Register of Marine Species website (WoRMS 2026).

Results

The 2,500 specimens collected in the village of La Arenosa, Gatun Lake, Chorrera, Panama, West, were small to medium in size (2-5 cm) and were classified as *C. fluminea*, Asian clam (Fig. 1). This species has a hard, rounded, triangular shell with well-defined concentric striations. Its periostracum is shiny and can vary in color from brown, greenish-golden, to almost black or yellowish tones. The inside of the shell has a lustrous finish in bluish tones, with a purplish outer edge and a pearly surface ranging from white to purple. In addition, it has three cardinal teeth and lateral denticulars. Its body is robust and has a large axe-shaped foot, which allows it to semi-bury itself in the substrate while filtering water to feed on organic particles present in soft sediments such as algae, microplankton and detritus. No obvious sexual dimorphism is observed, and this species is considered to have an inactive behavior.

Discusions

C. *fluminea*, known as the Asian clam, has established itself in Gatun Lake in Panama as an invasive species that competes for resources, alters food chains, and can block hydraulic infrastructure such as pipes and pumps. This is due to its high fecundity and accumulation capacity, which negatively impacts both water quality and native aquatic life. Its introduction into the region is believed to have been due to ballast water from ships, according to research into its local presence.

This species of freshwater clam has generated significant economic damage, amounting to millions of dollars for pipes used by various industries, including energy and water supply. Competition with *C. Fluminea* is causing a decline in the populations of many native species, as this clam spreads when it attaches to boats or is transported in ballast water. In addition, its use as bait has facilitated its sale within the aquarist trade (GISD, 2005). Native to Southeast Asia, specifically countries such as Russia, Thailand, the Philippines, Hong Kong, Taiwan, Korea, Japan (Britton and Morton, 1979 cited by CABI, 2013) and southern China (Morton, 1986 cited by Naranjo-

Vol. 6 (2) abril – septiembre 2026, pp. 101-114, ISSN-L 2710-7469

García & Olivera-Carrasco, 2014), C. *fluminea* continues to be a significant environmental problem in Panama.

It was first identified in the United States during the 1920s, and from there it spread to Mexico. In the 1970s, it began to appear in Brazil and Argentina, and from 1980 it was recorded in Venezuela. More recently, it has been reported in Ecuador, Peru and Panama. In Europe, its presence has been documented in countries such as France, Portugal, Germany, Belgium, the Netherlands, Spain, Hungary, Serbia and Ireland (Lucy *et al*., 2012). This species has been classified as invasive in several places: France, Japan and the United States (GISD, 2005), as well as in China, South Korea, the Philippines, Taiwan, Thailand, Canada, Panama, Argentina, Brazil, Uruguay and other European countries such as Belgium and the Czech Republic (CABI, 2013) as well as Spain (MAAMA, 2016). It was introduced to North America by Asian immigrants during the 1930s for the purpose of being used as food (Lucy *et al*., 2012). Juveniles can be transported globally by ballast water (GISD, 2005).

In various parts of the world this species is considered a pest due to its ability to proliferate rapidly. They are responsible for clogging pipes in industrial cooling systems and blocking the flow of water in irrigation and supply channels (Britton & Fuller, 1979 cited by Naranjo-García & Olivera-Carrasco, 2014). They also cause blockages in water-dependent water facilities and power plants. This happens mainly because juveniles have no ability to swim; they tend to enter various structures where they adhere to grow and reproduce until they cause obstructions with living individuals or shells of those that have died (CABI, 2013). In addition, they can block irrigation and drainage conduits during periods of low flow (GISD, 2005).

Actions and effects of the *C. fluminea* in Gatun Lake: this species acts as a filter feeder, consuming large volumes of plankton and competing directly with native species for food resources, which alters the base of the food web. Their proliferation in large quantities causes obstructions in filters, pumps and pipes of drinking water supply and electricity generation systems of the Panama Canal, generating operational problems. The massive presence of these clams can modify the composition of the sediment and displace local organisms, thus impacting biodiversity. Thanks to their high

Vol. 6 (2) abril – septiembre 2026, pp. 101-114, ISSN-L 2710-7469

fecundity and rapid growth, they have the ability to colonize new environments quickly. The introduction of this species in Panama and other areas of the world is mainly due to the ballast water used by ships sailing through the Canal, which facilitates its dispersal between different basins. The Asian clam present in Gatun Lake is an exotic organism that produces significant negative effects on both the ecosystem and the operations of the Panama Canal, serving as a clear example of the impact that invasive species can have on aquatic environments. In 1986, damage caused by *C. fluminea* in U.S. industries totaling approximately $1 billion (Isom, 1986 cited by Lucy *et al*., 2012; GISD, 2005). Likewise, it was estimated that damage to a nuclear plant reached $2.2 billion in 1980 (OTA, 1993 cited by CABI, 2013). In South America, problems related to fouling in power plants in Brazil have also been documented (Zampatti & Darrigan, 2001 cited by CABI, 2013).

Short-term management in Gatun Lake could be achieved through a variety of strategies. Manual removal of organisms is considered an effective method with minimal impact, although it is costly and requires a considerable number of human resources, and is more applicable in small areas. On the other hand, chemical controls are not feasible in open systems due to the impossibility of regulating the characteristics of water in large volumes and the potential risk of affecting other organisms. In closed systems, salinity can be increased (with a tolerable upper limit for this species between 14-17 ppm), the pH of the water can be modified (since below 5.6 the survival of the species is compromised), oxidizing biocides (such as chlorine or bromine) or non-oxidizing biocides (molluscicides, ammonium) can be applied, as well as potassium treatments can be applied (a high concentration causes the mollusc's foot to become immobilized when in contact with the treating agent). These methods have proven to be effective in controlling this species.

The populations of *C. Fluminea* are regulated using a variety of approaches. When these molluscs are in the water catchment tubes, thermal regulation is used, raising the temperature of the water inside the pipes above 37 °C; however, this method is not feasible in many systems. Mechanical measures, such as the use of screens and traps, can effectively remove adult clams and their body tissues along with shells. Low-temperature events can contribute to the population control of *C. fluminea*, while a rapid decrease in the water level in reservoirs could be used to manage this

Vol. 6 (2) abril – septiembre 2026, pp. 101-114, ISSN-L 2710-7469

invasive mollusk (Werner & Rothhaupt, 2008 cited by CABI, 2013). It is suggested to clean ships and barges that transport sediments. The proper and effective use of equipment such as dredgers and hand nets should include techniques such as washing with hot water (above 50 °C) and chlorine solutions (Aldridge & Muller, 2001 cited by CABI, 2013).

To control the spread of this species in Gatun Lake in the medium and long term, various measures could be implemented: establish regulations and infrastructures aimed at disinfecting boats and equipment, carry out constant monitoring of the dispersal of the species through prospecting campaigns, prohibit the sale of this organism in aquarium stores, promote native aquatic species by improving their habitat, facilitating their migration and restricting their fishing. It would also be beneficial to conduct environmental education campaigns focused on native naiads and develop specific programs to educate fishermen and farming communities.

The confirmed presence of *C. fluminea* in Gatun Lake establishes this Asian clam as a significant biological invader in Panama, with the potential to disrupt aquatic ecosystems and affect critical infrastructure such as the Panama Canal. Their remarkable reproductive capacity and rapid spread threaten native biodiversity, which demands constant environmental monitoring, according to studies carried out by the National University of Panama and international reports.

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