

Invasive macro-mollusks in lake Gatun: a major tributary of the Panama Interoceanic Canal

Macro-moluscos invasores en el lago Gatún: un afluente importante del Canal Interoceánico de Panamá

Darío Córdoba González

Universidad de Panamá, Facultad de Ciencias Naturales, Exactas y Tecnología, Panamá.

dario.cordoba@up.ac.pa <https://orcid.org/0000-0002-0693-4176>

Recepción: 14 de febrero de 2026. Aprobación: 30 de agosto de 2026

DOI: <https://doi.org/10.48204/semillaeste.v7n1.11386>

Abstract

Biological invasions represent a significant threat to the ecological integrity and economic functionality of the Panama Canal watershed. This study reports, for the first time, the occurrence and distribution of four invasive mollusk species, the bivalves *Corbicula fluminea* and *Potamocorbula amurensis*, and the gastropods *Melanoides tuberculata* and *Pomacea canaliculata*—within Lake Gatun and its surrounding tributaries (La Arenosa and Playa Leona). Monthly sampling conducted throughout 2025 at depths of up to 3 m yielded 9,800 specimens. Taxonomic identification confirmed the presence of *M. tuberculata* (n = 3,000), *P. canaliculata* (n = 3,100), *C. fluminea* (n = 2,500), and *P. amurensis* (n = 1,200). These species exhibit high reproductive plasticity and rapid colonization rates, potentially altering benthic nutrient cycling and posing a significant biofouling risk to the Panama Canal's hydraulic infrastructure. Our findings emphasize the urgent need for integrated management strategies and enhanced ballast water regulations to mitigate further ecological displacement in this globally significant transit corridor.

Keywords: Bivalves, clam, exotic species, invasive, Lake Gatun, Panama Canal

Resumen

Las invasiones biológicas representan una amenaza significativa para la integridad ecológica y la funcionalidad económica de la cuenca del Canal de Panamá. Este estudio reporta, por primera vez, la ocurrencia y distribución de cuatro especies de moluscos invasores —los bivalvos *Corbicula fluminea* y *Potamocorbula amurensis*, y los gasterópodos *Melanoides tuberculata* y *Pomacea canaliculata*— en el Lago Gatún y sus afluentes circundantes (La Arenosa y Playa Leona). Los muestreos mensuales realizados a lo largo de 2025 a profundidades de hasta 3 m arrojaron 9,800 especímenes. La identificación taxonómica confirmó la presencia de *M. tuberculata* (n = 3,000), *P. canaliculata* (n = 3,100), *C. fluminea* (n = 2,500) y *P. amurensis* (n = 1,200). Estas especies exhiben una alta plasticidad reproductiva y rápidas tasas de colonización, alterando potencialmente el ciclo de nutrientes bentónicos y representando un riesgo significativo de bioincrustación para la infraestructura hidráulica del Canal de Panamá. Nuestros hallazgos enfatizan la necesidad urgente de estrategias de manejo integrado y regulaciones mejoradas del agua de lastre para mitigar un mayor desplazamiento ecológico en este corredor de tránsito de importancia global.

Palabras clave: Bivalvos, almejas, especies exóticas, invasores, Lago Gatún, Canal de Panamá

Introduction

Lake Gatun is currently facing an unprecedented invasion of non-native mollusks and marine fish, facilitated by the expansion of the Panama Canal and increased seawater intrusion. Biological invasions represent one of the most significant ecological alterations on a global scale (Crespo et al., 2015). Within the context of current global changes, these invasions emerge as primary drivers of ecosystem shifts (Simberloff et al., 2013). Transitional ecosystems, particularly estuaries and artificial reservoirs, are highly susceptible to such events due to the density of human activities, including fisheries, ballast water discharge, and aquaculture (Cohen & Carlton, 1998; Williams & Grosholz, 2008). These areas serve as functionally important, highly productive habitats that dictate the river continuum dynamic (Vannote et al., 1980; Kennish, 2002; Sousa et al., 2010; Dolbeth et al., 2011; Hicks et al., 2011).

Because transitional waters are often characterized by low native diversity due to extreme physicochemical conditions and marine gradients (McLusky, 1993; Loo & Rosenberg, 1996; Kennish, 2002), the introduction of new species with highly competitive potential can have disproportionate effects on ecosystem functioning (Stachowicz & Byrnes, 2006; Sousa et al., 2008b; Pratt et al., 2014). The Asian clam, *Corbicula fluminea* (Müller, 1774) (Corbulidae), is among the most successful freshwater invaders globally (McMahon, 2002; DAISIE, 2008; Sousa et al., 2008a). It modifies the environment through energy assimilation and physical engineering, impacting hydrology, benthic communities, and biogeochemical cycles across the Neotropics and beyond (Phelps, 1994; Hakenkamp et al., 2001; Darrigran, 2002; Sousa et al., 2009; Atkinson et al., 2011). *C. fluminea* can tolerate salinities up to 10–14 (McMahon, 1983, 1999), allowing it to colonize upstream estuarine areas and establish satellite populations rapidly (Sousa et al., 2008b; Franco et al., 2012; Ilarri et al., 2014; Pascho et al., 2015).

Furthermore, *Potamocorbula amurensis* (Schrenck, 1861) has shown rapid expansion in systems like the San Francisco estuary, leading to critical decreases in phytoplankton biomass (Carlton et al., 1990; CABI, 2016). In Panama, gastropods such as *Melanoides tuberculata* (O. F. Müller, 1774) and *Pomacea canaliculata* (Lamarck, 1828) further complicate this landscape; the former acts as a vector for parasites

(Vogler et al., 2012), while the latter is a voracious herbivore that decimates aquatic vegetation (CABI, 2013). This study documents the presence of these species in Lake Gatun to predict their threat to the Panama Canal's freshwater extraction tunnels and overall hydraulic infrastructure.

Material and methods

Location of the study area: Lake Gatun (9°12' N, 79°4' W) is a critical artificial reservoir covering over 400 km². Sampling was focused on two primary sectors:

- La Arenosa: A freshwater sector in the district of Chorrera, used frequently for fishing and water activities.
- Playa Leona: A coastal-influenced area (08°50'50.53" N, 79°47'6.50" W) characterized by artisanal fishing and muddy sediments.

Field Methodology: Monthly sampling was performed throughout 2025. In Lake Gatun, specimens were collected via manual diving to depths of 3 m. At Playa Leona, bivalves were collected manually from the sediment of small streams and cattle farm pastures. All specimens were packaged in airtight containers and transported under refrigeration to the Museum of Malacology of the University of Panama (MUMAUP).

Laboratory Methodology: Following soft-tissue removal and oven-drying, specimens were identified based on shell morphology (aperture, siphonal canal, and muscle scars) using diagnostic keys by Keen (1971) and Coan and Valentich-Scott (2012). Taxonomic updates were verified via the World Register of Marine Species (WoRMS, 2026).

Results

A total of 9,800 individuals were analyzed. The distribution and characteristics of the identified species are detailed in Table 1.

Table 1.

Taxonomic classification, abundance, and key morphological features of invasive mollusks collected in the study areas.

Species	Class	Count (n)	Key Morphological Features
<i>Corbicula fluminea</i> (Müller, 1774)	Bivalvia	2,500	Triangular, heavy concentric ridges, glossy periostracum.
<i>Potamocorbula amurensis</i> (Schrenck, 1861)	Bivalvia	1,200	Thin, smooth valves; right valve overlaps left.
<i>Melanoidea tuberculata</i> (O. F. Müller, 1774)	Gastropoda	3,000	Conical, elongated shell; black body; operculated.
<i>Pomacea canaliculata</i> (Lamarck, 1828)	Gastropoda	3,100	Large, globose shell; thick operculum; amphibious respiration.

***Corbicula fluminea* (Asian Clam):** Identified by a triangular, rounded shell with prominent concentric striations and a glossy, golden-brown to black periostracum. The interior is pearly, ranging from white to purple. This species possesses high phenotypic plasticity, with shell characteristics varying across geographically close systems (Sousa et al., 2007; Vohmann et al., 2010; Rosa et al., 2012). Its dispersal is often facilitated by water currents and flotation mechanisms (Prezant & Chalermwat, 1984), while its capacity for androgenesis and self-fertilization ensures rapid establishment (Pigneur et al., 2011).

***Potamocorbula amurensis* (Amur River Clam):** Specimens were small (2–3 cm) with thin, yellowish-beige valves. The right valve slightly overlaps the left. Their introduction is likely linked to ship ballast water. *P. amurensis* shows high physiological tolerance to salinity variations and potential toxicants in both adult (Werner et al., 2003) and larval (Nicolini & Penry, 2000) stages. Its impact is severe due to its ability to colonize various habitats (Carlton et al., 1990) and withstand low oxygen levels (McEnnulty et al., 2001, as cited in GISD, 2005).

***Melanoidea tuberculata* (Trumpet Snail):** Characterized by an elongated, conical shell with deep grooves. This parthenogenetic gastropod can reach densities of several thousand individuals per m² (Dundee & Paine, 1977, as cited in CABI, 2013). First reported in the Miraflores Locks in 1971, it has now dispersed throughout the watershed, potentially displacing native snails and serving as a vector

for zoonotic parasites (Vogler et al., 2012).

***Pomacea canaliculata* (Apple Snail):** A large, globose snail (up to 100 mm) native to the Lower Paraná and La Plata basins. It is considered one of the "100 worst invasive species" due to its voracious herbivory. Unlike its relative *Pomacea bridgesii* (Reeve, 1856), which is relatively safe for aquatic plants, *P. canaliculata* is an agricultural pest that consumes essential local vegetation, altering the habitat structure.

Discussion

Management and Control Strategies

The Panama Canal as a Global Invasion Corridor: The presence of these four invasive taxa in Lake Gatun underscores the role of the Panama Canal as a high-pressure "bridgehead" for biological invasions. Unlike isolated freshwater bodies, Lake Gatun is a dynamic transit hub where high propagule pressure from international shipping intersects with a wide range of ecological niches. In the context of the Canal's expansion, the increased frequency of transits has accelerated the introduction of larvae via ballast water, directly facilitating the establishment of highly adaptable species like *P. amurensis* (Carlton et al., 1990; CABI, 2016).

Ecosystem Engineering and Trophic Cascades: The documented densities of *C. fluminea* and *P. amurensis* suggest a fundamental shift in benthic architecture. *C. fluminea* acts as an ecosystem engineer, modifying the sediment matrix through bioturbation and the production of empty shells, which alters benthic anthropogenic dynamics and creates new microhabitats (Teixeira et al., 2008; Ilarri et al., 2012, 2014). Furthermore, their high filtration rates can lead to significant phytoplankton depletion, outcompeting native mussels and altering reservoir nutrient cycling (Sousa et al., 2008a; Atkinson et al., 2011).

The gastropod component is equally disruptive. *P. canaliculata* poses a direct threat to the macrophyte communities stabilizing the lake's banks, risking a trophic cascade marked by increased turbidity and habitat loss for juvenile fish. Simultaneously, *M. tuberculata* reaches densities that displace native

snails through sheer biomass dominance (Vogler et al., 2012; CABI, 2013).

Synergistic Effects: Salinity and Climate Resilience: A critical factor in these invasions is the changing physicochemical profile of Lake Gatun. Increasing salinity gradients—driven by seawater intrusion and prolonged droughts—favor euryhaline invaders. *C. fluminea* exhibits notable resilience to environmental stressors, including copper toxicity, temperature fluctuations, and extreme flooding (Foe & Knight, 1985; Sousa et al., 2012b). While primarily a freshwater species, its tolerance to salinities up to 14 allows it to thrive in the transitional waters of the Canal's locks (McMahon, 1983, 1999). However, massive mortality events of *C. fluminea* under specific extreme conditions have been recorded elsewhere, which can temporarily degrade water quality through sudden organic loading (Sousa et al., 2012a).

Economic Implications and Biofouling: The "macrofouling" behavior of *C. fluminea* disables industrial water systems by clogging pipes and filters (Mattice, 1977; Rosa et al., 2011). In Lake Gatun, the accumulation of these mollusks in freshwater extraction tunnels and cooling systems necessitates integrated management to mitigate economic impacts (Table 2).

Management and Policy Recommendations: Eradication in an open system is often unfeasible once species reach the "establishment" phase. Management must focus on functional suppression:

- Ballast Water Management: Rigorous enforcement of international standards is the first line of defense (MAF, 2008).
- Early Detection and Rapid Response (EDRR): Utilizing the National Reference Collection at MUMAUP for regular monitoring.
- Public Education: Preventing accidental release from the aquarium trade is essential.

Table 2.

Integrated management strategies for controlling invasive mollusks in hydraulic infrastructure.

Method Type	Techniques	Targeted Species
Physical	Thermal control (hot water), suction/dredging, desiccation, mechanical filters.	<i>C. fluminea</i> , <i>P. amurensis</i>
Chemical	Oxidizing biocides (chlorine) and pH/salinity alteration in closed systems.	All (primarily infrastructure)
Biological	Introduction of natural predators (e.g., <i>Anentome helena</i> , <i>Botia</i> spp.).	<i>M. tuberculata</i> , <i>P. canaliculata</i>
Preventative	Ballast water treatment, equipment disinfection, aquarium release bans.	All

Conclusion

The establishment of these four invasive taxa in Lake Gatun poses a significant risk to the Panama Canal's operational efficiency and regional biodiversity. The mass reproduction of *C. fluminea* and *P. amurensis* represents a critical threat to cooling systems and water intakes. Continued monitoring and strict enforcement of ballast water management protocols (MAF, 2008; GISD, 2005) are essential to prevent the collapse of local aquatic ecosystems.

References

- Atkinson, C. L., Vaughn, C. C., Forshay, K. J., & Cooper, J. T. (2011). Aggregated filter-feeding consumers (Bivalvia: Unionidae) determine nutrient cycling in a freshwater system. *Journal of the North American Benthological Society*, 30, 210–221.
- CABI. (2013). *Melanoides tuberculata*. In: Invasive Species Compendium. CAB International, Wallingford, UK. www.cabi.org/isc
- CABI. (2016). *Potamocorbula amurensis*. In: Invasive Species Compendium. CAB International, Wallingford, UK. www.cabi.org/isc
- Carlton, J. T., Thompson, J. K., Schemel, L. E., & Nichols, F. H. (1990). Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. *Marine Ecology Progress Series*, 66, 81–94.
- Coan, E. V., & Valentich-Scott, P. (2012). *Bivalve Seashells of Western South America: Marine Bivalve Mollusks from Northern Peru to Southern Chile*. Santa Barbara Museum of Natural History.
- Cohen, A. N., & Carlton, J. T. (1998). Accelerating invasion rate in a highly invaded estuary. *Science*, 279, 555–558.
- Crespo, D., Dolbeth, M., Leston, S., Sousa, R., & Pardal, M. A. (2015). Distribution of *Corbicula fluminea* (Müller, 1774) in the Mondego estuary (Portugal): five years after its first record. *Aquatic Invasions*,

10, 377–389.

- DAISIE. (2008). *Delivering Alien Invasive Species Inventories for Europe*. European Commission, Sixth Framework Programme.
- Darrigran, G. (2002). Potential impact of filter-feeding invasive freshwater bivalves on benthic communities in the Neotropical Region. *Biological Invasions*, 4, 145–156.
- Dolbeth, M., Cusson, M., Sousa, R., & Pardal, M. A. (2011). Secondary production as a tool for better understanding of aquatic ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences*, 68, 1230–1253.
- Dundee, D. S., & Paine, A. C. (1977). Ecology of the snail *Melanoides tuberculata* (Muller), intermediate host of the human liver fluke (*Opisthorchis sinensis*) in New Orleans, Louisiana. *The Nautilus*, 91, 17–20.
- Foe, C., & Knight, A. (1985). Further studies of the toxicity of copper to *Corbicula fluminea* with notes on its interactions with temperature and salinity. *Hydrobiologia*, 120, 81–88.
- Franco, J. N., Ceia, F. R., Patrício, J., Modesto, V., Thompson, J., Marques, J. C., & Neto, J. M. (2012). Population dynamics of *Corbicula fluminea* (Müller, 1774) in south-western Europe reveals anthropogenic impact. *Marine Environmental Research*, 80, 31–39.
- GISD. (2005). *Global Invasive Species Database*. Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission.
- Hakenkamp, C. C., Ribblett, S. G., Palmer, M. A., Swan, C. M., Reid, J. W., & Goodison, M. R. (2001). The impact of an introduced bivalve (*Corbicula fluminea*) on the benthos of a sandy stream. *Freshwater Biology*, 46, 1107–1114.
- Hicks, N., Bulling, M. T., Solan, M., Paterson, D. M., Pieromeni, M., Arndt, S., & Stahl, H. (2011). Impact of climate change on the biodiversity-ecosystem function nexus in anthropogenic coastal ecosystems. *Environmental Science & Technology*, 45, 9144–9151.
- Ilarri, M. I., & Sousa, R. (2012). *Corbicula fluminea* Müller (Asian clam). In R. A. Francis (Ed.), *A Handbook of Global Freshwater Invasive Species* (pp. 173–183). Earthscan.
- Ilarri, M. I., Antunes, C., Guilhermino, L., & Sousa, R. (2012). Massive mortality of the Asian clam *Corbicula fluminea* in a highly invasive population. *Biological Invasions*, 14, 2019–2024.
- Ilarri, M. I., Souza, A. T., Modesto, V., Guilhermino, L., & Sousa, R. (2014). Influence of the invasive Asian clam *Corbicula fluminea* on vertical distribution of mobile benthic fauna. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 24, 610–621.
- Keen, A. M. (1971). *Sea Shells of Tropical West America: Marine Mollusks from Baja California to Peru* (2nd ed.). Stanford University Press.
- Kennish, M. J. (2002). Environmental threats and environmental future of estuaries. *Environmental Conservation*, 29, 78–107.

- Loo, L. O., & Rosenberg, R. (1996). Anthropogenic organic enrichment and nutrients — some effects on the herbivorous macrofauna in the Gullmarsfjord, western Sweden. *Oceanologica Acta*, 19, 115–126.
- MAF. (2008). *Biosecurity New Zealand: Early detection and monitoring of Potamocorbula amurensis*. Ministry of Agriculture and Forestry, Wellington.
- Mattice, J. S. (1977). Interactions of submerged macromolecules with the surfaces of *Corbicula*. *Proceedings of the First International Corbicula Symposium*, Texas Christian University, Fort Worth.
- McEnnulty, F. R., Bax, N. J., Schaffelke, B., & Campbell, M. L. (2001). *A review of rapid response options for the control of ABWMA listed introduced marine pest species and related taxa in Australian waters*. Centre for Research on Introduced Marine Pests.
- McLusky, D. S. (1993). Marine and estuarine gradients — An overview. *Netherlands Journal of Aquatic Ecology*, 27, 489–493.
- McMahon, R. F. (1983). Ecology of an invasive pest bivalve, *Corbicula*. In W. D. Russell-Hunter (Ed.), *The Mollusca, Vol. 6, Ecology* (pp. 505–561). Academic Press.
- McMahon, R. F. (1999). Invasive characteristics of the freshwater bivalve *Corbicula fluminea*. In R. Claudi & J. H. Leach (Eds.), *Nonindigenous Freshwater Organisms: Vectors, Biology and Control* (pp. 315–346). Lewis Publishers.
- McMahon, R. F. (2002). Evolutionary and physiological adaptations of aquatic invasive animals: r-selection versus resistance. *Canadian Journal of Fisheries and Aquatic Sciences*, 59, 1235–1244.
- Nicolini, M. H., & Penry, D. L. (2000). Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. *Pacific Science*, 54, 377–388.
- Pascho, L. M., Andrade, D. P., & Pires-Junior, O. R. (2015). First record of *Corbicula fluminea* (Müller, 1774) in the Paranoá Lake, Brasília, Brazil. *Brazilian Journal of Biology*, 75, 101–107.
- Phelps, H. L. (1994). The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River Estuary near Washington, D.C. *Estuaries*, 17, 614–621.
- Pigneur, L. M., Hedtke, S. M., Etoundi, E., & Van Doninck, K. (2011). Androgenesis: a strategy to avoid genetic load in invasive *Corbicula* clams? *Heredity*, 107, 15–25.
- Pratt, D. R., Lohrer, A. M., Thrush, S. F., Hewitt, J. E., Townsend, M., & Reed, J. (2014). Assessing disturbance history using biodiversity-ecosystem function relationships. *Ecosphere*, 5, 1–18.
- Prezant, R. S., & Chalermwat, K. (1984). Flotation of the bivalve *Corbicula fluminea* as a means of dispersal. *Science*, 225, 1491–1493.
- Rosa, I. C., Garrido, R., Inda, S., Rocha-Barreira, C. A., Angelini, N., & Casanueva, M. E. (2011). Biofouling

- p>by
- Corbicula fluminea*
- in a hydroelectric power plant in southern Brazil.
- Annals of the Brazilian Academy of Sciences*
- , 83, 1–12.
- Rosa, I. C., Pereira, J. L., Costa, R., Gonçalves, F., & McManus, J. (2012). The influence of temperature on the behavior and survival of the invasive bivalve *Corbicula fluminea*. *Journal of Thermal Biology*, 37, 233–239.
- Simberloff, D., Martin, J. L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J., Courchamp, F., ... & Vilà, M. (2013). Impacts of biological invasions: what's next? *Trends in Ecology & Evolution*, 28, 58–66.
- Sousa, R., Antunes, C., & Guilhermino, L. (2007). Variation of the physiological condition of *Corbicula fluminea* (Müller, 1774) in the Minho River estuary (NW Iberian Peninsula). *Estuarine, Coastal and Shelf Science*, 73, 551–557.
- Sousa, R., Antunes, C., & Guilhermino, L. (2008a). Ecology of the invasive Asian clam *Corbicula fluminea* (Müller, 1774) in aquatic ecosystems: an overview. *Annales de Limnologie - International Journal of Limnology*, 44, 85–94.
- Sousa, R., Nogueira, A. J., Gasper, M. C., Antunes, C., & Guilhermino, L. (2008b). Growth and changes in condition index of *Corbicula fluminea* (Müller 1774) in the Minho estuary: anthropogenic and natural influences. *Iheringia, Série Zoologia*, 98, 204–211.
- Sousa, R., Ilarri, M., Guilhermino, L., & Antunes, C. (2009). Ecology of *Corbicula fluminea* (Müller, 1774) in the River Minho estuary: a review after 20 years of invasion. *Aquatic Invasions*, 4, 277–289.
- Sousa, R., Dias, S., & Antunes, C. (2010). Spatial and temporal distribution of *Corbicula fluminea* (Müller, 1774) in the River Minho estuary. *Scientia Marina*, 74, 111–120.
- Sousa, R., Varandas, S., Cortes, R., Teixeira, A., Lopes-Lima, M., Machado, J., & Guilhermino, L. (2012a). Massive mortality of *Corbicula fluminea* (Müller, 1774) in a European river: causes and ecological consequences. *Science of the Total Environment*, 435, 156–161.
- Sousa, R., Novais, A., Costa, R., & Guilhermino, L. (2012b). Effects of extreme floods on the distribution of *Corbicula fluminea*. *Hydrobiologia*, 696, 1–9.
- Stachowicz, J. J., & Byrnes, J. E. (2006). Species diversity, invasion success, and ecosystem functioning: disentangling the influence of resource competition, facilitation, and extrinsic factors. *Marine Ecology Progress Series*, 311, 251–262.
- Teixeira, H., Salas, F., & Marques, J. C. (2008). A benthic perspective of the anthropogenic changes in the Mondego estuary (Portugal) over the last two decades. *Marine Pollution Bulletin*, 56, 648–665.
- Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 130–137.
- Vogler, R. E., Beltramino, A. A., Sede, M. M., Gregoric, D. E. G., Núñez, V., & Rumi, A. (2012). The invasive apple snail *Pomacea canaliculata* in Paraguay: morphology, DNA barcoding, and its role as a potential



vector of *Angiostrongylus cantonensis*. *Check List*, 8, 229–233.

- Vohmann, A., Borchering, J., Kureck, A., Deneke, A., & Arndt, H. (2010). Strong impact of the invasive clam *Corbicula fluminea* on vertical distributions of sediment micro-organisms and meiofauna. *Biological Invasions*, 12, 1367–1377.
- Werner, I., Clark, S. L., & Hinton, D. E. (2003). Biomarkers of sublethal stress in the invasive bivalve *Potamocorbula amurensis* from the San Francisco Bay Estuary, USA. *Marine Pollution Bulletin*, 46, 481–490.
- Williams, S. L., & Grosholz, E. D. (2008). The invasive species challenge in estuarine and coastal environments: Marrying management and science. *Estuaries and Coasts*, 31, 3–20.
- WoRMS Editorial Board. (2026). *World Register of Marine Species*. Accessed 08 April 2026. doi:10.14284/170.