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Short Communication

The first record of an Asian mangrove, *Heritiera fomes* Banks (Malvaceae: Sterculioideae), occurring outside of cultivation in Ecuador and the Americas

***Natalia Molina-Moreira*[1,2]*, *Roberto R. Román*[2], *Laurence J. Dorr*[3], *Efraín Freire*[2] & *Álvaro Torres-Domínguez*[1,4]**

[1]*Universidad Espíritu Santo, Samborondon, Ecuador.*
[2]*Instituto Nacional de Biodiversidad, Quito, Ecuador.*
[3]*Smithsonian Institution, National Museum of Natural History, Department of Botany, MRC-166, DC 20013-7012, Washington, USA.*
[4]*Ministerio de Ambiente, Agua y Transición Ecológica, Quito, Ecuador.*
**Corresponding author: natimolina@uees.edu.ec*

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Abstract: The first record of an Asian mangrove, *Heritiera fomes* Banks (Malvaceae: Sterculioideae), occurring outside of cultivation in Ecuador and the Americas is documented. The species was discovered in 2022 on Santay Island in the Gulf of Guayaquil, Ecuador, where it is naturalized and produces flowers and fruits at least twice per year. Populations were located on both the shore and in inland areas on the northern part of the island, which is directly influenced by fresh water from the Babahoyo and Daule rivers. *Heritiera fomes* co-occurs with native species in both mangrove swamp and dry forest. As many as 0.45 individuals/m^2 were observed. How the species was introduced into Ecuador is unknown. However, given the similarity of the environmental conditions of Santay Island to those of the native range of *H. fomes*, its invasive potential in Ecuador is of concern and discussed.
Keywords: *Exotic species; Invasive; Santay Island*.

El primer registro de un mangle asiático, *Heritiera fomes* Banks (Malvaceae: Sterculioideae), existiendo fuera del cultivo de Ecuador y las Américas

Resumen: El primer registro de un manglar asiático, *Heritiera fomes* Banks (Malvaceae: Sterculioideae), el cual ocurre fuera del cultivo en Ecuador y las Américas. La especie fue encontrada en 2022 en la Isla Santay en el Golfo de Guayaquil, Ecuador, donde parece estar naturalizada y produce flores y frutos al menos dos veces al año. Se descubrieron varias poblaciones en la parte norte de la isla, que está directamente influenciada por el agua dulce de los ríos Babahoyo y Daule. *Heritiera fomes* se encuentra tanto en la costa como áreas de la isla donde crece junto a especies nativas de manglar y bosque seco. Se observaron hasta 0.45 individuos/m^2. Se desconoce cómo se introdujo la especie. Sin embargo, dadas la similitud de las condiciones ambientales de la Isla Santay a las del hábitat de *H. fomes,* su potencial de invasión en Ecuador es motivo de preocupación y se discute.
Palavras-chave: *Especies exóticas; Invasoras; Isla Santay*.

Introduction

Introduced species are a global problem due to their impacts on biodiversity conservation (Fei et al. 2014). Some studies suggest that they are the second leading cause of biodiversity loss after habitat fragmentation (Mosquera et al. 2022). Biological invasions occur when a species is introduced from a biogeographically isolated region by human activities, establishes a self-sustaining population, and expands its range (Richardson & Pyšek 2006; Blackburn et al. 2011).

Mangroves, which form a coastal intertidal ecosystem present in the tropics and subtropics, are not exempt from invasions (Krauss & Ball 2013). Until recently the inherent salinity, anoxia, and wave conditions impacting mangrove ecosystems were thought to prevent invasion by alien species (Biswas et al. 2018). However, multiple reports of invasive species are known now for mangroves, and they cause reduced natural regeneration, increased sedimentation, and reduced biodiversity (Fei et al. 2014; Fazlioglu & Chen 2020). Most of these introductions have been accidental (>80%); many fewer have been intentional (~18%) and

these latter often are from a desire to take advantage of the benefits of mangroves (e.g., soil stabilization and coastal protection) (Chowdhury et al. 2016; Biswas et al. 2018).

Mangrove species also can be invasive (Fazlioglu & Chen 2020). The impact of exotic mangrove species on mangrove ecosystems varies according to the site. For example, *Sonneratia apetala* Banks on Hainan Island, China, improved microenvironmental conditions and favored the recruitment of native mangroves (Xin et al. 2013). In contrast, *Laguncularia racemosa* (L.) C.F.Gaertn. on the same island displaced the native mangrove *Rhizophora apiculata* Blume (Fazlioglu & Chen 2020). On Molokai Island in Hawaii, *R. mangle* L. and *Conocarpus erectus* L. replaced exotic species established more than a century ago, generating a completely new plant formation on the island and possibly altering ecological processes (Allen 1998).

It has been suggested that tidal dynamics create and vacate multiple microhabitats of low salinity and waves, increasing susceptibility to invasion by invasive non-halophyte and facultative halophyte species (Krauss & Ball 2013; Sarker et al. 2019). In Ecuador, this susceptibility could be exacerbated when considering the high anthropic pressure observed in mangroves; pressure created by aquaculture and urbanization (Morocho et al. 2022).

Santay Island is a delta located at the mouths of the Babahoyo and Daule rivers and receives a flow of 1600 $m^3 s^{-1}$ of fresh water, exhibiting salinity levels of up to 4.2 ppm (Arreaga Vargas 2000; Villegas et al. 2021). These low salinity conditions have favored the invasion in the vicinity of the island of non-halophyte alien species such as *Eichhornia crassipes* (Mart.) Solms, as well as native dry forest woody taxa such as *Entada polystachya* (L.) DC., *Mimosa pigra* L., and *Erythrina fusca* Lour. (personal observation).

Recently, an exotic mangrove, *Heritiera fomes* Banks, was discovered in the northern part of Santay Island, an area directly influenced by the Babahoyo and Daule rivers. In its native range in Asia, *H. fomes* although extensive in its distribution is considered a threatened species due to progressive declines in populations caused by expansion of the agricultural frontier and exploitation of its wood (Kathiresan et al. 2010; Chowdhury et al. 2016; Khan et al. 2020). In the world's most extensive mangrove formation, the Sundarbans, *H. fomes* dominates hypo- and meso-saline habitats forming monospecific stands and clearly prefers upstream sites (i.e., freshwater-dominated river systems) (Iftekhar & Saenger 2008; Sarker et al. 2016). Given the similarity of the environmental conditions of its native habitat to that of Santay Island, in terms of salinity and tidal patterns as well as traits related to invasive species (high fecundity, high survivability of seeds), *H. fomes* potentially represents a threat to the native flora of the island and its surroundings. Given these concerns, the objective of this research was to describe the current distribution of *H. fomes* on Santay Island in order to provide baseline ecological data.

Materials and Methods

1. Study area

Santay Island is a 2,215 ha delta located at the mouth of the Guayas River (2°13'26"S, 79°51'22"W) (Figure 1). It is bounded on the west by the city of Guayaquil and on the east by Durán and is impacted directly by industrial and agricultural wastewater from both these municipalities (Deknock et al. 2019). Until 1980, before the island was expropriated by the Ecuadorian government, it was an area of intensive livestock and agricultural activity (Zambrano Moreira et al. 2019). At present, these activities have been replaced by tourism that was facilitated by the construction of bridges to connect the island with both Guayaquil and Durán.

At least three plant formations can be distinguished in the area: (a) mangroves (i.e., *Avicennia germinans* (L.) L., *Conocarpus erectus*, *Laguncularia racemosa*, and *Rhizophora* spp.), with *Annona glabra* L., and wetland grasslands that include the fern *Tectaria fernandensis* C.Chr., which dominate the shores and frequently flooded areas; (b) shrubby elements of dry forests (e.g., *Erythrina fusca*, *Entada polystachya*, and *Mimosa pigra*) in inland areas with less flooding frequency; and (c) in the transitions between these formations, where meadows dominated by exotic and native species (e.g., *Hymenachne* sp., *Paspalum* sp., *Cyperus* sp., and *Uniola pittieri* Hack.) are observed, interspersed with patches of emergent palm trees (*Roystonea oleracea* (Jacq.) O.F.Cook and *R. regia* (Kunth) O.F.Cook) that grow to 40 m tall.

2. Discovery and identification

In early 2022, park rangers from the Isla Santay National Recreation Area noticed the presence of an unfamiliar plant similar to a mangrove in the northern part of the island (2°11'48"S, 79°51'8"W). Given their initial observation and taking advantage of field work conducted as part of a larger project focused on mangroves of Ecuador, fertile samples of the plant were collected to determine its taxonomic identity. Voucher specimens were made from June 2022 to January 2023, which corresponds to the dry season in this area.

These vouchers were deposited in the National Herbarium of Ecuador (QCNE) in Quito where this unknown plant tentatively was identified as an unknown genus and species of Malvaceae (Sterculioideae). Photographs were sent to one of us (LD) who confirmed that the family and subfamily were correct and who recognized the plant as a species of *Heritiera* Aiton, which is not native to the Americas. Once specimens were provided, the unknown "mangrove" was identified as *H. fomes* (Figure 2). Although the authorship of this species name often is attributed to Francis Buchanan-Hamilton (abbreviated as "Buch.-Ham."), the preface to Symes (1800), where the name was first published, states that "Sir Joseph Banks selected and described the plants." Therefore, the correct author citation is Banks.

Around the locality where *Heritiera fomes* was first found, land surveys were conducted in a radius of 1 km to determine the distribution of the species on the island. Simultaneously, flooded areas near and around the island were surveilled by boat. In both cases, all observed occurrences of the species were georeferenced. In this process, two more populations of *H. fomes* were located to the southwest of the original site discovered by park rangers, at 100 and 300 m distance respectively from the shore (Figure 1).

3. Abundance, density, and habitat

To estimate population density, 10 × 10 m plots were installed in each of the three identified populations. All individuals present in each plot were censused. Individuals with a basal diameter less than 1 cm measured at 5 cm above the ground were considered seedlings

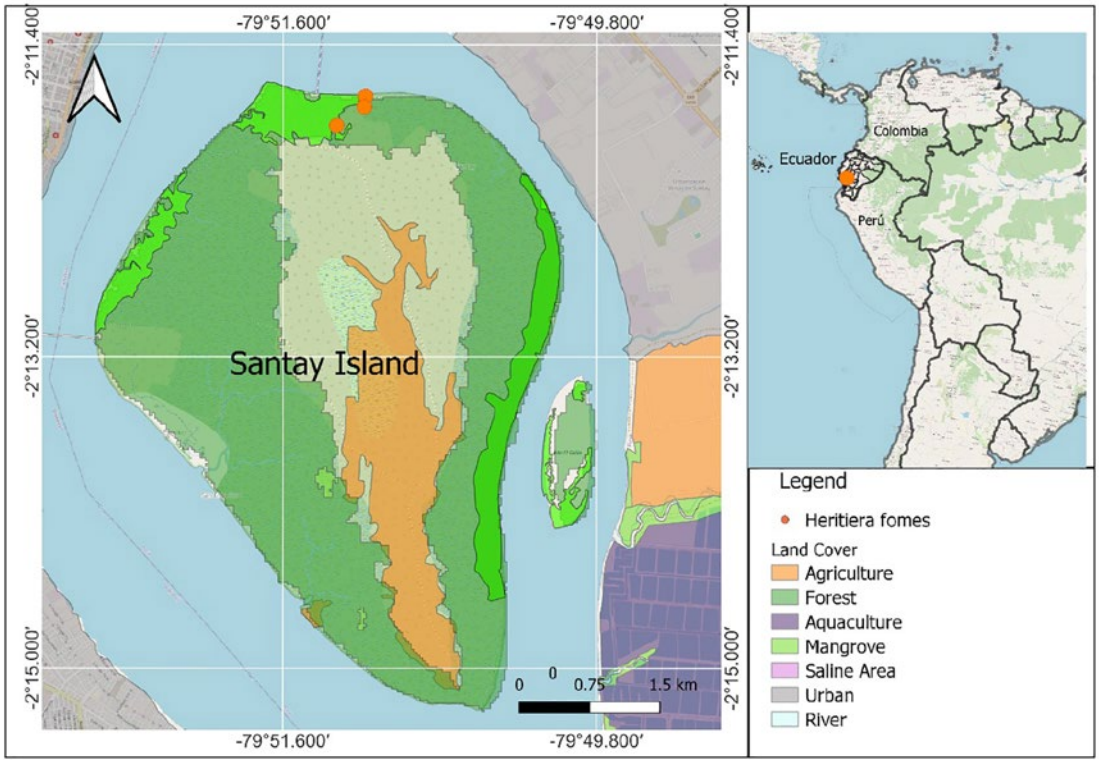


Figure 1. Map of Santay Island, Ecuador showing the areas where *Heritiera fomes* occurs. (Layers of land use and political boundaries were obtained from Open Street Map, Ecosystem Classification System of Continental Ecuador, and the Military Geographic Institute; see Google Street Contributors 2024; Instituto Geográfico Militar 2023; Ministerio del Ambiente del Ecuador 2012).

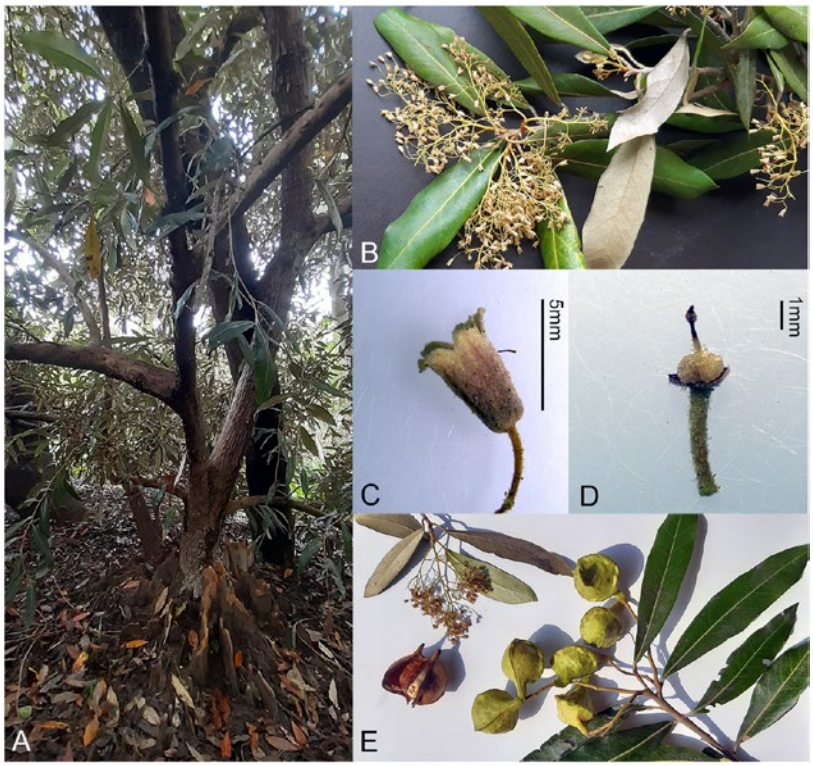


Figure 2. *Heritiera fomes* on Santay Island, Ecuador. – A. Habit of mature tree (note plank buttresses at base). – B. Inflorescence and leaves. – C. Flower. – D. Staminate flower with calyx removed (note the androgynophore and subapical ring of anthers). – E. Inflorescence (upper left), infructescence (right) with green fruit, and a single detached older fruit (lower left) (note the irregular knobby surface and transverse ridges on the green fruit, which are characteristic of *H. fomes*).

(Chen et al. 2010; Wahyuningtyas et al. 2022), individuals with a diameter >1 cm and with woody stems branched from the ground were considered shrubs, and individuals with woody stems not branched above the ground were considered trees. The habit and diameter of all individuals were recorded, and height was estimated; diametric tapes were used to measure the diameter and an aerial pruner to estimate the height. For trees and shrubs, the diameter was measured at 1.3 m above the ground (DBH) and in seedlings diameter was measured at 5 cm above the ground (Wahyuningtyas et al. 2022). In addition, associated plant taxa, habitat, water level, and canopy cover were recorded for each site. The data were digitized using Libreoffice version 7.3.2.2. The processing, analysis, and mapping of the data were conducted in the statistical programming software R version 4.1.3 using the tidyverse, sf, and ggspatial packages (R Core Team 2022).

Results

In total, 14 trees, 16 shrubs, and 51 seedlings of *Heritiera fomes* were recorded in the three plots. *Heritiera fomes* was observed with flowers in June, July, November, and December, and with fruits in December and January. The abundance, between adults and seedlings, was 64 individuals on the shore, nine individuals from 9 to 100 m distance from the shore, and eight individuals at 300 m from the shore. The density of seedlings was highest on the shore with up to 0.45 seedlings/m^2 observed. Seedling density decreased as the distance from the shore increased, registering 0.05 seedlings/m^2 at 300 m from the shore. Additionally, seedlings were found at a distance of between 0.3 to 4 m from a parent plant.

The average height of the trees was 8.79 m with some individuals reaching more than 13 m (Table 1). Notably, branching patterns varied according to habitat with the number of branching forks being higher in areas with high frequency of flooding. Shrubs measured an average of 2.68 m tall and did not exceed 5 m, while seedlings reached an average of 0.42 m in height. With respect to diameter, trees had the greatest range of variation, from 5 to 23 cm DBH, but in general they averaged 13.26 cm DBH. Shrubs had an average diameter of 4.38 cm, although several individuals were found with diameters less than 3 cm.

Regarding habitat, *Heritiera fomes* had an abundance of 72 individuals in areas with high frequency of flooding, while in areas with less frequent flooding, where soil compaction and the frequency of dry forest taxa are higher, abundance dropped to nine individuals. In general, shrubs but not trees and seedlings tend to be present in habitats with higher canopy cover, although in all three habitats individuals are likely to be found both in areas without canopy cover and in areas with up to 90% cover (Table 2). Seedlings tend to be more frequent in habitats with low water levels, while trees and shrubs can be present both in dry areas as well as flooded and swampy areas.

Within *Heritiera fomes* populations different taxa associated with each life form were observed. Seedlings were mostly associated with *Avicennia germinans*, *Crinum kunthianum* M.Roem., and *Rhizophora racemosa* G.Mey. (Table 3). Shrubs occurred mainly in areas where *Laguncularia racemosa*, *Sphagneticola trilobata* (L.) Pruski, and *C. kunthianum* were present. Trees were more abundant in areas where *A. germinans* and *Roystonea oleracea* occurred.

Table 1. Measures of central tendency and dispersion of the variables DBH (cm) and Height (m) for each life form recorded for *Heritiera fomes* on Santay Island.

Life form	n	Min	Max	Mean	SD
DBH					
seedling	51	0.5	0.7	0.56	0.08
shrub	16	2.0	9.5	4.38	2.27
tree	14	5.0	23.0	13.26	6.92
Height					
seedling	51	0.4	0.5	0.42	0.04
shrub	16	1.0	5.0	2.68	1.35
tree	14	6.0	15.0	8.79	3.24

Table 2. Measures of central tendency and dispersion of the variables Canopy cover (%) and Water level (cm) for each life form recorded for *Heritiera fomes* on Santay Island.

Life form	n	Min	Max	Mean	SD
Canopy cover					
seedling	51	12	90	46.16	21.23
shrub	16	0	90	71.38	30.91
tree	14	0	80	43.00	26.76
Water level					
seedling	51	5	100	9.31	18.57
shrub	16	5	100	49.38	35.44
tree	14	5	100	51.43	44.22

Table 3. Identity of taxa and number of individuals found close to occurrences of *Heritiera fomes* for each life form on Santay Island.

Species	Seedling	Shrub	Tree
Albizia multiflora (Kunth) Barneby & J.W.Grimes	0	5	0
Avicennia germinans (L.) L.	43	4	11
Crinum kunthianum M.Roem.	32	6	3
Entada polystachya (L.) DC.	2	1	1
Erythrina fusca Lour.	0	1	2
Laguncularia racemosa (L.) C.F.Gaertn.	6	9	1
Passovia pedunculata (Jacq.) Kuijt	2	1	1
Rhizophora mangle L.	0	0	1
Rhizophora racemosa G.Mey.	32	3	5
Roystonea oleracea (Jacq.) O.F.Cook	11	5	6
Sphagneticola trilobata (L.) Pruski	0	6	1
Tectaria fernandensis C.Chr.	0	2	1

Discussion

The native range of *Heritiera fomes* is discontinuous. It is found in the Bay of Bengal where it occurs extensively near the mouth of the Ganges and Brahmaputra rivers in India and Bangladesh and in the Andaman Sea where it occurs at the mouth of the Irrawaddy (type locality) and Great Tenasserrim rivers in Myanmar and further south in peninsular Thailand (Kostermans 1959a, 1959b; Spalding et al. 1997; Malick 1991; Phengklai 2001; Rahman et al. 2012). Reports of the natural occurrence of this species in the Andaman Islands are suspect and probably represent misidentifications of *H. littoralis* Aiton (Phengklai 2001; POWO 2024).

In its native habitat, *Heritiera fomes* is a tree 15–25 m tall and 1.5–28 cm in DBH and is considered endangered (Kathiresan et al. 2010). Historically, larger trees of up to 2 m in circumference existed but they have mostly been harvested impacting the species in its natural distribution (Troup 1921; Hossain & Nizam 2002; Kathiresan et al. 2010). Trunks have prominent plank buttresses and after ca. three years the trees produce pneumatophores. Fruits on trees in India and Bangladesh measure 3.8–5.1 × 2.5–3.8 cm (Hossain & Nizam 2002). The species is found on the land side of mangrove forests (Spalding et al. 1997) because it does not tolerate regular flooding and prefers slightly to moderately saline areas (Hossain & Nizam 2002; Mandal et al. 2021). In the dense forest of *H. fomes*, the understory is practically absent (Hossain & Nizam 2002).

How *Heritiera fomes* arrived in Ecuador is unknown. Long distance dispersal seems unlikely. Drift from the Bay of Bengal and the Andaman Sea in the Indian Ocean would not find its way easily to the Pacific Ocean and once there, it would have to enter the South Pacific Subtropical Gyre, be carried north along the coast of South America in the Peru Current, and then make its way through the Gulf of Guayaquil to the northern end of Santay Island. A more likely explanation for the introduction of *H. fomes* is that its fruit inadvertently was transported from Asia to Ecuador by cargo ship. There is active ship commerce between these two areas and an incidental introduction is a possibility since the fruit of *H. fomes* has the ability to float. Venegas Vinueza (2010) documented exports and imports between India and Ecuador from 2005 to 2009 and the principal mode of transport was maritime with the main port of entry Guayaquil. In the last 25 years there has been an increase in exports from Ecuador to Bangladesh (OEC 2024). As of 2011, trade began to grow between Ecuador and Asian countries such as Myanmar and Thailand, among others (Coba 2019). Nonetheless, we cannot rule out an intentional introduction of *H. fomes* by ship's crew since the species has been used for medicinal purposes to treat stomach and skin conditions and to treat diabetes (Mahmud et al. 2014).

There is a single historical record of *Heritiera fomes* cultivated in the Americas. In the late 18th and early 19th centuries the species was cultivated in Trinidad, an island in the Caribbean. The sole collection known, *W.E. Broadway 796*, is vouchered by leaves and loose fruit collected in 1907 from a tree planted ca. twenty years earlier. Vouchers are deposited in the Université Claude Bernard Lyon 1 (leaves: LY [barcodes LY0151635, LY0151635, & LY0151637]; see also https://www.gbif.org/occurrence/3427793841) and in the Muséum national d'Histoire Naturelle, Paris (fruit: P [barcode P02443774]; see also https://www.gbif.org/occurrence/3436227327). Another collection of *Heritiera* made in the Botanic Gardens, Trinidad (*W.E. Broadway s.n.*, US [barcode 03383553]) although distributed as *H. fomes* was misidentified and is, in fact, *H. littoralis* (personal observation).

1. When did Heritiera fomes become established on Santay?

When *Heritiera fomes* became established on Santay Island is unknown. The size of the trees and the number of plants suggest it has been present for ca. 15–20 years. Flowering and fruiting are abundant, plants establish and grow easily, and although the species has only been found at three sites, they are all places where the environmental conditions are more similar to the native habitat of the species than elsewhere on the island. Notably, the northern part of the island is rich in sediments deposited by the Babahoyo and Daule rivers.

2. Invasive potential of Heritiera fomes

In native hyposaline habitats, the DBH of *Heritiera fomes* increases between 1.08 and 1.3 mm yr-1, reaching up to 25 m, which signifies it is a fast-growing species (Iftekhar & Saenger 2008; Chowdhury et al. 2016). *Heritiera fomes* flowers between March and August, and bears fruit between April and September. As much as 40% of the litter produced by the species corresponds to reproductive organs, which suggests that *H. fomes* allocates a large part of its biomass to reproduction (Azad et al. 2020; Mariam & Alamgir 2022). The germination of its seeds and the survival of its seedlings increases up to 96% and 25%, respectively, in hyposaline environments showing its preference for this type of habitat (Sarker et al. 2016; Mariam & Alamgir 2022). *Heritiera fomes* exhibits high SLA (Specific Leaf Area) and LI (Leaf Index) phenotypic plasticity under different light and salinity conditions; traits related to a broad ecological niche and shade tolerance (He et al. 2018; Khan et al. 2020). In fact, on Santay Island, *H. fomes* has established itself near species such as *Roystonea oleracea* and *Samanea saman* (Jacq.) Merr., which are species that compact the soil and produce constant shade, and also in completely uncovered habitats, thus showing a high range of tolerance to light and to competition with other species.

High growth rates, high fecundity, high phenotypic plasticity, hydrochory, and a persistent seed bank are linked to inherent traits of invasive species in wetlands (Zedler & Kercher 2004; Pyšek & Richardson 2007; Blackburn et al. 2011). In fact, it has been suggested that high SLA values and growth rates could be predictors of invasive species (Grotkopp & Rejmánek 2007). In this context, it is logical to suggest that mangroves located upstream with high freshwater flow are more susceptible to plant invasions; in fact, most of the invasive plants reported in the world are non-halophytes (Biswas et al. 2018).

In light of the traits exhibited by *Heritiera fomes* in its native habitat, it is prudent to consider its invasive potential on Santay Island. Environmental conditions (e.g., salinity < 2 dS m^{-1} and low waves) are similar to its native habitat in Sundarbans (Sarker et al. 2019). Nonetheless, it is ironic that in its native range, *H. fomes* is now considered to be an endangered species primarily due to overexploitation of its timber, which raises a paradox regarding its occurrence on Santay Island. This paradox can be explained by considering conditions on the island. Freed from biotic (e.g., competitors, predators, and diseases), abiotic (e.g., high salinity and waves), and anthropogenic pressures, *H. fomes* could improve its survivability on the island. This scenario has been observed in

Laguncularia racemosa in China, which, being free from salt stress and having a wide phenotypic plasticity has been able to displace native species (Gu et al. 2019; Fazlioglu & Chen 2020).

Invasive species are one of the greatest threats to biodiversity in the world. The report of new records of exotic species is important to prevent and mitigate the effects of a potential invasive species and prepare future actions to favor native biodiversity. The impact of *Heritiera fomes* on the native flora and fauna in Ecuador is uncertain and will require longitudinal studies to assess its impact on biodiversity. *Heritiera fomes* possesses several traits that qualify it as an invasive species. The environmental conditions in the Guayas River are conducive to its adaptability as they are like those of its native habitat. Although *H. fomes* is found currently only on Santay Island, favorable conditions exist throughout the Gulf of Guayaquil and suggest that further efforts are needed to locate and, if discovered, monitor the species in other areas. By doing so, we can better understand and manage its potential impact on the region's ecosystem.

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Author Contributions

Natalia Molina-Moreira: conceptualization; methodology; writing-original draft; writing-review and editing.

Roberto R. Román: conceptualization; methodology; writing-original draft; writing-review and editing.

Laurence J. Dorr: conceptualization; writing-original draft; writing-review and editing.

Efraín Freire: writing-original draft.

Álvaro Torres-Domínguez: methodology.

Conflicts of Interest

The authors declare that they have no conflicts of interest related to the publication of this manuscript.

Ethics

This study did not involve human beings and/or clinical trials that should be approved by an Institutional Committee.

Data Availability

Voucher specimens for the presence of *Heritiera fomes* in Ecuador were deposited in the National Herbarium of Ecuador (QCNE) in Quito and the U.S. National Herbarium (US) in Washington, DC. The primary data analyzed during the current study are reported in the main text as Tables 1–3. The authors confirm that all data necessary for reproducing the study findings are available in the designated dataset.

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