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Checklist of Non-Native Aquatic Plants in Up, Middle and Downstream of Brantas River, East Java, Indonesia

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ABSTRACT

The development of a checklist of non-native aquatic plants in the Brantas River is very important from an ecological perspective. The checklist of non-native aquatic plants provides valuable information for the development of effective management and mitigation strategies. The main objective of this study was to provide a detailed checklist of non-native aquatic plants present in the Brantas River, East Java, Indonesia. Sampling was conducted at several locations along the river, where site selection included differences in habitat and environmental conditions, from Blitar (upstream), Trenggalek (midstream), Kediri (midstream), and Jombang (downstream). At each selected site, five 1 x 1m quadrats were randomly placed along the riverbank and within the waterbody using a stratified random allocation within each habitat type (shallow area, slow-flowing section, tributary mouth). Comprehensive identification of physiological and ecological characteristics of non-native species was based on published books and scientific journals. The result of this research showed that there are several non native invasive aquatic plants in Brantas River, viz. the alligator weed, Ludwigia, water lettuce, floating fern, frogbit, parrot feather, Hydrilla, Ambulia, Lemna, water chestnut, Cabomba, and the water hyacinth, Azolla. We recommend management control through mecanical, biological and chemical alternative.

INTRODUCTION

Non-native aquatic plants are plant species outside their native or natural range that have been introduced into a new ecosystem **(Lozano, 2021)**, such as the Brantas River in East Java, Indonesia, but are not native to the environment. This introduction can occur through human activities, such as the aquarium trade, aquaculture, agriculture, transportation and other intentional or unintentional methods **(Montagnani *et al.*, 2022)**. Once introduced, non-native aquatic plants have the potential to have a major impact on the local ecology **(Strayer, 2020)**.

One significant consequence is the competition they pose to native plant species **(Wandrag & Catford, 2020)** for important resources such as sunlight, nutrients and space. The disturbance caused by non-native plants can lead to changes in the natural balance of the aquatic ecosystems **(Flood *et al.*, 2020)**. Native species, which have evolved and adapted to specific environmental conditions will be severely disadvantaged when faced with the aggressive growth and rapid colonization of non-native plants. This competition may result in the displacement of native flora, leading to a reduced biodiversity and potential loss of important habitats for various aquatic organisms **(Hughes *et al.*, 2020; Tallamy *et al.*, 2020)**. The introduction of non-native aquatic plants can disrupt the physical, chemical, and biological structure of the aquatic environment **(Occhipinti-Ambrogi, 2021)**.

The Brantas River, located in East Java, Indonesia, has a diverse and complex ecological system **(Fadjar *et al.*, 2019; Hasan *et al.*, 2020)**. The river supports a wide range of aquatic life, including a variety of plant species that contribute to the health and function of the aquatic ecosystem at large. Like most open waters, the ecological balance along the Brantas River basin is vulnerable to disturbance. Regular monitoring is essential to manage and maintain it, especially in relation to the introduction of non-native aquatic plants.

The development of a checklist of non-native aquatic organism in the Brantas River is very important from an ecological perspective **(Isroni *et al.*, 2019; Islamy & Hasan, 2020; Masithah & Islamy, 2023; Islamy *et al*., 2024**). Identification and assessment of these non-native species allows the evaluation of their potential impact on physico-chemical and biological aspects of native waters. The checklist of non-native aquatic plants provides valuable information for the development of effective management and mitigation strategies. Immediate action is needed to prevent and control the spread of non-native aquatic plants in order to maintain the ecological integrity of the Brantas River. The main objective of this study was to provide a detailed checklist of non-native aquatic plants present in the Brantas River, East Java, Indonesia. Through systematic surveys and analysis, we sought to identify and document the various non-native plant species within the river ecosystem. In addition, this study aimed to provide a descriptive comparative analysis between non-native and native plants. This comparative approach would deepen the understanding of the potential ecological disturbance caused by non-native species, thus aiding the formulation of conservation and management strategies for the Brantas River. The results of this study are expected to make a valuable contribution to the conservation and sustainable ecological management of the Brantas River.

MATERIALS AND METHODS

Study area

The presence and distribution of non-native aquatic plants in the Brantas River, East Java, Indonesia, was assessed through various methods in this study. Systematic surveys were conducted to identify and document various non-native plant species within the river ecosystem. Moreover, sampling was conducted in several locations along the river (Fig. 1), where site selection includes differences in habitat and environmental conditions from from Blitar (upstream), Trenggalek (midstream), Kediri (midstream), and Jombang (downstream) (Fig. 1).

Fig. 1. Map of sampling area in Brantas River

Procedures

At each selected site, five 1 x 1m quadrats were randomly placed along the riverbank and within the waterbody using a stratified random allocation within each habitat type (shallow area, slow-flowing section, tributary mouth). This provided spatially representative data within each site. Data collection involved careful observation and recording of plant species, abundance and distribution. Moreover, samples were photographed and then collected for laboratory analysis. Average abundance of plants was determined using published methods **(Isroni *et al.*, 2019)**. Furthermore, comprehensive identification of physiological and ecological characteristics of non-native species was based on published books and scientific journals about aquatic plants.

RESULTS

The result of this research show that there are several non native invasive aquatic plants in the Brantas River, viz. the alligator weed, Ludwigia, water lettuce, floating fern, frogbit, parrot feather, Hydrilla, Ambulia, Lemna, water chestnut, Cabomba, and water hyacinth, Azolla (Table 1 & Fig. 3).

Table 1. Non- native invasive aquatic plants in the Brantas River recorded during the study

Family	Genus	Common name	Avg. Abundance (inds/m²)	Distribution in Brantas River
Pontederiaceae	Eichhornia	Water hyacinth	325	Widespread across all locations
Araceae	Pistia	Water lettuce	112.5	Common in slow-moving sections of Blitar, Kediri, Jombang
	Lemna	Lemna	200	Widespread across all locations, particularly Trenggalek & Jombang
Amaranthaceae	Alternanthera	Alligator weed	75	Primarily riverbanks & shallow areas of Blitar & Trenggalek
Cabombaceae	Cabomba	Cabomba	37.5	Scattered throughout all locations, except Jombang
Haloragaceae	Myriophyllum	Parrot feather	100.25	Common in slow-moving sections of Trenggalek, Kediri & Jombang
Hydrocharitaceae	Hydrilla	Hydrilla	75	Widespread across all locations, except Jombang
Lythraceae	Trapa	Water chestnut	22.5	Scattered in shallow areas of Trenggalek & Kediri
Menyanthaceae	Nymphoides	Frogbit	17.5	Scattered in shallow areas of Blitar & Trenggalek
Onagraceae	Ludwigia	Ludwigia	100.25	Common in slow-moving sections of all locations
Plantaginaceae	Limnophila	Ambulia	15	Scattered in slow-moving sections of Blitar & Kediri
Salviniaceae	Salvinia	Floating fern	75	Scattered throughout all locations, except Jombang
	Azolla	Azolla	112.5	Widespread across all locations, particularly Kediri & Jombang

The abundance

The abundance and distribution data of various aquatic plants in the Brantas River, offer valuable insights into the current state of the river's ecosystem. The water hyacinth appears to be the most prevalent species, with an average abundance of 325 individuals per square meter and widespread distribution across all locations. This aligns with published research highlighting the water hyacinth's invasive nature and ability to form dense mats, impacting water flow and biodiversity. Similarly, the water lettuce, Lemna, and the parrot feather show notable abundance, particularly in specific sections, reflecting their adaptability to slow-moving waters. These findings correlate with existing studies on the preferences of these species for such environments.

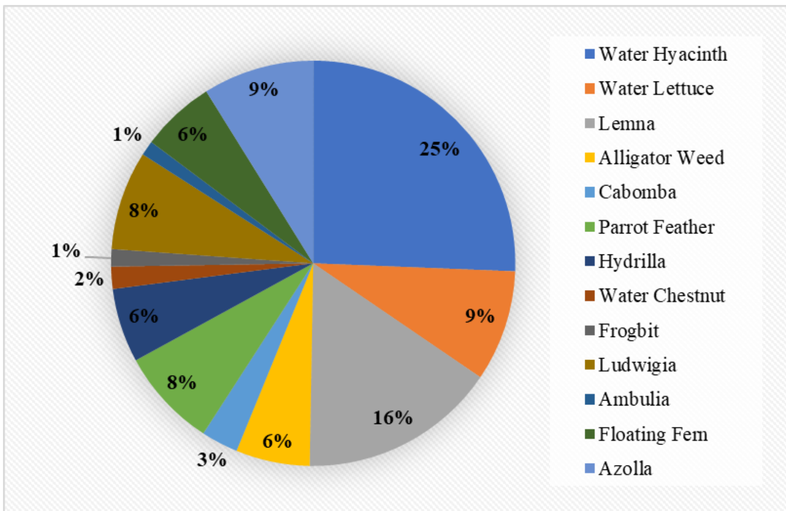

Fig. 2. The abundance data of various aquatic plants in the Brantas River

In contrast, the alligator weed and Cabomba exhibit lower average abundances and more localized distributions, primarily along riverbanks and shallow areas in Blitar, Trenggalek, and Kediri. These patterns align with research indicating the preference of these species for specific habitats. Hydrilla, although widespread, has a slightly lower average abundance, suggesting the presence across various locations but not as dominant as the water hyacinth. Moreover, the water chestnut and frogbit exhibit scattered distributions in shallow areas, consistent with their preferences for such habitats.

Ludwigia and Azolla show a high average abundance, especially in slow-moving sections, affirming their adaptability to these conditions. Ambulia and floating fern have lower average abundances and scattered distributions in slow-moving sections, aligning with their preferences for specific environments. The recorded data for these species correspond to the existing knowledge about their ecological preferences and invasive potential.

Fig. 3. A: Alligator weed; **B:** Ludwigia; **C:** Water lettuce; **D:** Floating fern; **E:** Frogbit; **F:** Parrot feather; **G:** Hydrilla; **H:** Ambulia; **I:** Lemna; **J:** Water chestnut; **K:** Cabomba ; **L:** Water hyacinth; **M:** Azolla. (Photo by: JBM Silitonga, J Sihombing, M Indah; and AR Wahid)

DISCUSSION

Alligator weed (Fig. 3A)

Description: Alligator weed is a perennial herbaceous plant that originates from South America **(Tanveer & Usman, 2022)**. It belongs to the amaranth family (Amaranthaceae) and is recognized for its rapid growth and invasive characteristics **(Abbas *et al.*, 2022)**. Alligator weed is a semi-aquatic plant that can thrive in both terrestrial and aquatic environments. It typically has fleshy stems with opposite leaves that are lance-shaped and arranged in pairs. The plant produces inconspicuous white flowers and can form dense mats along waterways.

Potential ecological impact: Alligator weed is considered an invasive species in many regions where it has been introduced. Its potential ecological impact includes the formation of dense mats that can crowd out native vegetation, reducing biodiversity. These mats can alter water flow, affecting aquatic habitats and potentially leading to the displacement of native plant species. Additionally, the presence of alligator weed can impact water quality, and it may serve as habitat for certain pests and diseases. The invasive potential of alligator weed is attributed to its ability to reproduce rapidly and form dense colonies. It can spread through water movement, human activities, and by floating stem fragments. Moreover, alligator weed is known to colonize both aquatic and terrestrial habitats, making it adaptable to various environments. Human activities, such as the unintentional introduction of stem fragments through equipment or intentional planting for erosion control, can contribute to its spread.

Biology: Alligator weed reproduces through various methods, including seeds, stem fragments, and root fragments **(Tanveer *et al.*, 2018; Zhong *et al.*, 2019)**. The plant can produce flowers, but it often reproduces more efficiently through vegetative means. Stem fragments can root easily, allowing the plant to spread rapidly. This capability for vegetative reproduction contributes to the invasiveness of alligator weed.

Ludwigia (Fig. 3B)

Description: Ludwigia is a genus of aquatic and semi-aquatic plants that includes both submerged and emergent species. Most species (80%) are native to the New World although the genus is pantropical with some (largely naturalized) representation in temperate Europe, Africa, and Eurasia **(Kurniadie *et al.*, 2021)**. These plants are characterized by their lance-shaped or oval leaves and can vary in color from green to red, depending on the species and environmental conditions. Ludwigia species are commonly found in freshwater habitats, including ponds, lakes, and slow-moving rivers. Some species of Ludwigia are popular in the aquarium trade for their ornamental value.

Potential ecological impact: While Ludwigia species can play a natural role in aquatic ecosystems, some have the potential to become invasive when introduced to non-native environments. Invasive Ludwigia **(Kurniadie *et al.*, 2021; Reddy *et al.*, 2021)** can form dense stands, outcompeting native vegetation and altering the structure of aquatic habitats. The dense growth can reduce light penetration and oxygen exchange in the water, affecting the growth of other aquatic plants and potentially impacting the overall biodiversity of the ecosystem. The invasive potential of Ludwigia species varies among different species. Some Ludwigia species have been reported as invasive in certain regions, particularly when introduced to non-native water bodies **(Kurniadie *et al.*, 2021;**

Reddy *et al.*, 2021). Human activities, such as the release of aquarium plants into natural water bodies, unintentional transport on boats, or intentional planting for landscaping purposes, can contribute to the introduction and spread of invasive Ludwigia. Once established, Ludwigia can be challenging to control due to its rapid growth and efficient vegetative reproduction.

Biology: Ludwigia species reproduce through both sexual and vegetative means **(Ferreira *et al.*, 2021; Lemus *et al.*, 2021)**. The plants produce flowers that can be either solitary or arranged in clusters, depending on the species. Ludwigia also reproduces vegetatively through stem fragments and runners. Many Ludwigia species are known for their ability to root and grow rapidly from stem fragments, contributing to their potential invasiveness.

Water lettuce (Fig. 3C)

Description: *Pistia stratiotes* (water lettuce, the Nile cabbage) originates in South America and is the only species in the Araceae that floats freely on still or slow-moving water bodies **(Coetzee *et al.*, 2020; Jaklič *et al.*, 2020)**. Water lettuce (*Pistia stratiotes*) is a free-floating aquatic plant with a rosette-like arrangement of leaves that resembles a floating head of lettuce. Native to tropical and subtropical regions, water Lettuce is known for its distinctive appearance and its ability to form dense mats on the water's surface. The leaves are light green, often covered with fine hairs, and have a spongy texture that aids in buoyancy.

Potential ecological impact: While the water lettuce is often used ornamentally in water gardens and aquariums, it has the potential to become invasive in natural water bodies **(Milićević, 2023; Wen *et al.*, 2023)**. The formation of dense mats on the water surface can lead to several ecological impacts. These mats reduce sunlight penetration into the water, affecting the growth of submerged plants and algae. The shading effect can alter the composition of aquatic communities, impacting the abundance and diversity of fish and other organisms. Additionally, the dense mats may impede water flow, potentially leading to stagnant conditions and affecting oxygen levels. The water lettuce has the potential to be invasive in suitable aquatic environments **(Nahar & Hoque, 2021; Wen *et al.*, 2023)**. It can spread quickly, forming dense mats that cover the water surface. Human activities, such as the release of water Lettuce from ornamental ponds and aquariums, contribute to its introduction into new areas. Once established, the plant is capable of rapid growth, especially in nutrient-rich waters. Its ability to reproduce vegetatively further enhances its invasive potential, as new plants can develop from fragments and stolons.

Biology: The water lettuce reproduces through both sexual and vegetative means **(Adomako *et al.*, 2020; Coetzee *et al.*, 2020)**. It produces small flowers arranged on a spike, with both male and female flowers present on the same plant. The plant can also reproduce vegetatively through stolons and daughter plants that develop from the base of the parent plant. The ability to reproduce rapidly through both sexual and vegetative methods contributes to its potential invasiveness.

Floating fern (Fig. 3D)

Description: Floating ferns, such as Salvinia, are characterized by their floating leaves that form a velvety layer on the water's surface. They are native to a relatively small area in southeastern Brazil **(Coetzee, 2020)**. Salvinia species typically hs two types of leaves – one submerged and root-like, and the other floating on the water. The floating leaves have a unique structure with tiny hairs that repel water, giving them a water-resistant appearance. These ferns are often used in aquariums and water gardens for their decorative qualities.

Potential ecological impact: While Salvinia species is popular in controlled environments, they have the potential to become invasive when introduced to non-native ecosystems **(Kashe *et al.,* 2020; Kariyawasam *et al.,* 2021)**. The dense mats formed by floating ferns can cover the water surface, limiting sunlight penetration and affecting the growth of submerged plants. This alteration of light availability can impact the overall structure and function of aquatic habitats, potentially leading to changes in biodiversity and ecosystem dynamics. Floating ferns, especially Salvinia species, are known for their invasive potential **(Wahl *et al.,* 2021)**. They can spread quickly, forming dense mats that cover the water's surface. Human activities, such as the release of aquarium plants into natural water bodies, unintentional transport on boats, or intentional planting for water management purposes, can contribute to the introduction and spread of floating ferns. Once established, they can be challenging to control due to their rapid growth and efficient vegetative reproduction.

Biology: Salvinia species reproduce through both sexual and vegetative means **(Coelho *et al.,* 2023)**. The plants produce spore-bearing structures that release spores into the water. These spores can germinate and develop into new plants under suitable conditions. Additionally, Salvinia can reproduce vegetatively through the fragmentation of the floating leaves. Even small fragments can give rise to new plants, contributing to their rapid spread.

Frogbit (Fig. 3E)

Description: Frogbit (*Limnobium laevigatum*) is a free-floating aquatic plant that belongs to the Hydrocharitaceae family. Native to parts of South America **(García-Murillo, 2023)**, Frogbit is recognized for its rounded, floating leaves and delicate white flowers. The plant forms dense mats on the water's surface and is commonly found in slow-moving or still freshwater habitats. Frogbit is popular in the aquarium trade but has the potential to become invasive in natural water bodies.

Potential ecological impact: While the frogbit plant is often valued in aquariums for its ornamental qualities, it can have ecological impacts when introduced to non-native environments **(Hansen *et al.,* 2022; Rutherford *et al.,* 2022)**. The formation of dense surface mats can reduce light penetration into the water, affecting the growth of submerged plants and potentially altering the habitat structure. This shading effect, along with the physical coverage of the water surface, can influence the composition and functioning of aquatic ecosystems, impacting native species and biodiversity. Frogbit has the potential to be invasive in certain environments, especially when introduced to non-native water bodies **(Zhu *et al.,* 2018)**. The plant spreads rapidly through vegetative reproduction, forming dense floating mats. Human activities, such as the release of the frogbit from aquariums or unintentional transport on boats and equipment, can contribute to its introduction and spread. Once established, the frogbit can be challenging to control due to its rapid growth and efficient vegetative propagation.

Biology: Frogbit reproduces through both sexual and vegetative means **(Hansen *et al.,* 2022)**. The plant produces small, inconspicuous white flowers on long stems that emerge above the water surface. The flowers can be either male or female. The frogbit primarily reproduces vegetatively through the production of daughter plants connected to the parent plant by stolons. These daughter plants eventually detach and become independent. This efficient vegetative reproduction contributes to the potential invasiveness of the frogbit.

Parrot feather (Fig. 3F)

Description: The parrot feather (*Myriophyllum aquaticum*) is a submerged aquatic plant belonging to the Myriophyllum genus. *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae), commonly known as the parrot feather, is an invasive aquatic macrophyte from South America that is regarded as a major international aquatic weed **(Goddard *et al.,* 2022)**. It is commonly known for its distinctive feather-like foliage. The plant features whorls of finely divided, bright green leaves that emerge above the water's surface when it grows in shallow water. The parrot feather is native to South America but has been introduced to various regions globally, both intentionally for ornamental purposes and unintentionally through aquatic trade.

Potential ecological impact: The parrot feather has the potential to have significant ecological impacts when introduced to non-native environments **(Gross *et al.,* 2020)**. The plant forms dense mats on the water's surface, inhibiting light penetration and potentially displacing native aquatic vegetation. This can alter the structure of aquatic habitats, impact nutrient cycling, and affect the overall biodiversity of the ecosystem. The parrot feather may also create favorable conditions for certain mosquito species, potentially influencing local disease dynamics. Moreover, parrot feather is considered invasive in several regions due to its ability to establish quickly and to form dense stands **(Gross *et al.,* 2020)**. It can spread through water currents, fragments transported by animals or equipment, and intentional planting for ornamental purposes. The plant is adaptable to a variety of aquatic environments, including ponds, lakes, and slow-moving streams, contributing to its invasive potential. Once established, the parrot feather can be challenging to control and eradicate due to its vigorous growth and efficient vegetative reproduction.

Biology: The parrot feather reproduces through both sexual and vegetative means **(Kumwimba *et al.,* 2020)**. The plant produces inconspicuous flowers on emergent stems, with male and female flowers occurring on separate plants. However, in many cases, the parrot feather primarily reproduces vegetatively. Stem fragments can take root and develop into new plants, allowing for rapid colonization and spread. The ability to propagate vegetatively contributes to its potential invasiveness.

Hydrilla (Fig. 3G)

Description of Hydrilla: Hydrilla is a submerged, aquatic perennial plant characterized by freely branching stems that root in the substrate. Stem nodes and fragments can develop adventitious roots. The sessile leaves are linear to lanceolate, whorled in groups of four to eight, and range from 6 to 19mm in length, featuring toothed margins visible to the naked eye. Slender, unbranched roots develop ovoid tubers at the tips, which are tough, white to brown-black, and approximately 19mm long. The plant produces male and female flowers that float on long, thread-like tubes, with translucent and white to red sepals and petals. Male flowers detach at maturity, floating on the water surface to release pollen. North American biotypes exhibit both monoecious and dioecious characteristics **(Tippery, 2023)**.

Potential ecological impact: The hydrilla plant can have significant ecological impacts on community composition, structure, and interactions **(Gentilin-Avanci *et al.*, 2020)**. It forms dense mats near the water surface, intercepting sunlight and displacing native aquatic plants. This can reduce the seed production of native species and alter phytoplankton composition. The hydrilla adversely affects fish populations, provides habitats for mosquito species, slows water movement causing flooding, degrades water quality, increases sedimentation rates, and affects water nutrient turnover. Hydrilla can establish in undisturbed aquatic communities **(Tippery, 2023)**, and the mechanical disturbances increase the chances of establishment. Turions and tubers can germinate in complete darkness, with optimal germination occurring at low light intensities. Hydrilla is adaptable to a wide range of aquatic habitats, tolerating both low and high nutrient waters, low salinity, and a broad pH range **(Ефремов *et al.*, 2019)**. While it thrives in warm climates, it can exhibit significant photosynthetic activity at temperatures as low as 10.5°C. There are no known weedy Hydrilla species in North America.

Biology: The hydrilla reproduces sexually through seeds and vegetatively through fragmentation, tubers, and turions (axillary leaf buds) **(Patrick & Florentine, 2021)**. Turions, being small and lightweight, are well-suited for dispersal, while tubers, formed terminally on rhizomes, are heavier and better adapted for winter survival. Tubers can survive ingestion by waterfowl, facilitating long-distance dispersal.

Ambulia (Fig. 3H)

Description: *Limnophila sessiliflora*, known as Ambulia, is an aquatic plant with delicate, feathery leaves that are arranged in whorls along the stem. The plant is characterized by its fast growth and ability to adapt to various aquatic environments. In aquariums. Ambulia is often used to add a lush, green background to the tank. *Limnophila* (family: Scrophulariaceae) is originated from a *Latin* word that means pond-loving indicating its existence in aquatic environments. It is commonly known as 'Ambulia' (Asian marshweed). It is a perennial from tropical to subtropical Africa, Australia, and the Pacific Islands; also finds adventive distribution in North America **(Brahmachari *et al.*, 2013)**.

Potential ecological impact: While Ambulia (*Limnophila sessiliflora*) is popular in the aquarium trade, it has the potential to become invasive when introduced to non-native ecosystems. Invasive Ambulia can form dense stands, outcompeting native vegetation and altering the structure of aquatic habitats **(Patoka *et al.*, 2018)**. The shading effect of the dense growth can impact the growth of submerged plants and influence the overall biodiversity of the ecosystem. The invasive potential of Ambulia (*Limnophila sessiliflora*) depends on several factors **(Koncki & Aronson, 2015)**, including local environmental conditions and human activities. It is often introduced unintentionally into natural water bodies through the release of aquarium plants or the disposal of aquarium water. Once established, Ambulia can spread rapidly, forming dense populations and potentially displacing native vegetation.

Biology: *Limnophila sessiliflora* reproduces through both sexual and vegetative means. The plant produces small, inconspicuous flowers on emergent stems, with male and female flowers occurring on separate plants. The flowers can set seeds under favorable conditions. Additionally, Ambulia can propagate vegetatively through the formation of lateral shoots and the branching of stems. This efficient vegetative reproduction contributes to the potential invasiveness of Ambulia.

Lemna (Fig. 3I)

Description: Lemna is a genus of small, free-floating aquatic plants commonly known as duckweeds. They are native to Europe and North America **(Hussner, 2012)**. These plants belong to the Lemnaceae family and are characterized by tiny, flat, leaf-like structures called fronds. Lemna species are among the smallest flowering plants and are often found in still or slow-moving freshwater environments. The fronds are typically green and can reproduce rapidly, forming dense colonies on the water's surface.

Potential ecological impact: While the Lemna species are generally considered a natural component of aquatic ecosystems, they have the potential to become invasive under certain conditions. Dense mats of Lemna can alter the light and nutrient availability in the water, affecting the growth of submerged plants and other aquatic organisms. This may lead to changes in the composition and structure of the aquatic community, impacting the overall ecosystem dynamics. Additionally, Lemna can create stagnant conditions beneath its mats, affecting oxygen levels in the water **(Paolacci *et al.*, 2018)**. Potential invasiveness of Lemna has been studied worldwide **(Armando *et al.*, 2021)**. The invasive potential of Lemna is associated with its ability to reproduce rapidly and form dense colonies on the water's surface. Lemna species can spread easily through water currents, wind, or by attaching to the bodies of animals. Human activities, such as unintentional introduction through contaminated equipment or intentional release from aquariums and ornamental ponds, can contribute to the spread of Lemna. Once established, Lemna can be challenging to control due to its rapid growth and efficient asexual reproduction.

Biology: Lemna reproduces primarily through asexual and sexual means **(Ho *et al.*, 2019)**. The plants can multiply rapidly through budding, where daughter fronds develop from the parent frond. This asexual reproduction allows Lemna to form dense colonies quickly. While Lemna species does produce flowers, sexual reproduction through seeds is less common and not as significant in the overall reproductive strategy. The small flowers are often inconspicuous and produce seeds that can be dispersed to new locations.

Water chestnut (Fig. 3J)

Description: The water chestnut (*Trapa natans*) is an aquatic plant known for its distinctive floating rosettes of triangular, serrated-edged leaves and submerged, nut-like fruits. It is native to Asia and Europe but has become invasive in various parts of North America **(Fernandes *et al.*, 2022)**. The water chestnut grows in freshwater habitats, forming dense mats on the water's surface. The plant's floating rosettes create a green carpet-like appearance on the water.

Potential ecological impact: The water chestnut has the potential to cause significant ecological impacts when introduced to non-native environments. They are very invasive **(Chorak *et al.,* 2019)**. The formation of dense mats can outcompete native aquatic plants, reduce light penetration, and alter the structure of aquatic habitats. These changes can impact the abundance and diversity of native flora and fauna, potentially leading to declines in biodiversity **(McKeon *et al.,* 2022)**. The water chestnut can also interfere with recreational activities, navigation, and water management practices. Moreover, water chestnut is highly invasive **(McKeon *et al.,* 2022)**, with the potential to spread rapidly in new environments. The plant produces a large number of seeds, and the floating fruits help disperse them over water surfaces. Additionally, the ability to form daughter rosettes through vegetative reproduction allows the water chestnut to colonize and cover large areas of water bodies. Human activities, such as the transport of seeds on boats or the inadvertent release of plant fragments, contribute to its spread.

Biology: The water chestnut reproduces through both sexual and vegetative means **(McKeon *et al.,* 2022)**. The plant produces small, white flowers with four petals that emerge above the water. The fruits, resembling chestnuts, develop underwater. Each fruit contains a single seed and four sharp spines. The water chestnut primarily reproduces vegetatively through the formation of daughter plants connected to the main rosette by stolons. This vegetative reproduction contributes to the rapid spread of the plant.

Cabomba (Fig. 3K)

Description: Cabomba is a genus of aquatic plants that is a notorious invasive aquatic weed native to South America **(Roberts & Florentine, 2021)**, and is one of the well-known species *Cabomba caroliniana*, commonly called Carolina fanwort or simply Cabomba. It is characterized by finely dissected, fan-shaped leaves that are arranged in whorls along the stem. The leaves are typically submerged, and the plant has a delicate appearance. Cabomba is popular in the aquarium trade but has also been introduced to natural water bodies, where it can become invasive.

Potential ecological impact: Cabomba has the potential to have ecological impacts, especially when introduced to non-native environments. The cabomba species is highly invasive **(Roberts & Florentine, 2021)**. In invaded areas, Cabomba can form dense stands that outcompete native aquatic vegetation. The dense growth can alter the habitat structure, reduce light availability, and impact the nutrient dynamics of the water. These changes can, in turn, affect the composition and functioning of the aquatic ecosystem, potentially leading to declines in native species diversity. Cabomba has demonstrated invasive potential in areas where it has been introduced **(Jingyu *et al.,* 2019)**. The plant can be spread unintentionally through the release of fragments during waterway activities, such as boating or fishing, or intentionally as an ornamental plant in aquariums. Once established in a new environment, Cabomba can form dense colonies, creating challenges for native flora and fauna. Its ability to grow rapidly and reproduce through various mechanisms enhances its invasive potential.

Biology: Cabomba reproduces through both sexual and vegetative means **(Bickel, 2016)**. The plant produces flowers with white to pale purple petals. Cabomba is capable of both self-pollination and cross-pollination, contributing to its reproductive success. The plant can also propagate vegetatively through stem fragments. The combination of sexual and vegetative reproduction allows *Cabomba* to establish and spread rapidly in suitable environments.

Water hyacinth (Fig. 3L)

Description: Water hyacinth (*Eichhornia crassipes*) is a free-floating aquatic plant known for its vibrant green leaves and beautiful lavender flowers. It is native to South America but has become widely distributed in tropical and subtropical regions around the world **(Cherwoo *et al.*, 2024)**. The plant has bulbous, spongy petioles that enable it to float on the water's surface, and its roots dangle freely in the water.

Potential ecological impact: Water hyacinth is considered one of the most invasive aquatic plants globally **(Singh *et al.*, 2020)**. Moreover, its rapid spread can have severe ecological impacts **(Thamaga & Dube, 2018)**. The plant forms dense mats on the water's surface, blocking sunlight and oxygen from reaching the underlying water. This leads to decreased oxygen levels, negatively affecting fish and other aquatic organisms. The dense mats also impede water flow, increasing the risk of flooding in affected areas. Additionally, the presence of water hyacinth alters the physical and chemical properties of the water, impacting the composition and functioning of aquatic ecosystems. The invasive potential of water hyacinth is attributed to its ability to reproduce rapidly and form dense mats on the water's surface. The plant can thrive in various aquatic environments, from slow-moving rivers to still ponds. Human activities, such as the release of the plant from ornamental ponds and its accidental introduction during waterway transport, contribute to its global spread. Once established, water hyacinth is challenging to control, as mechanical removal often leads to the fragmentation of plants and further spread.

Biology: ThewWater hyacinth reproduces through both sexual and vegetative means **(Gaikwad & Gavande, 2017)**. It produces attractive lavender flowers with a distinctive yellow spot, and these flowers can give rise to seeds. However, the primary mode of reproduction is vegetative, through stolons and daughter plants that develop from the base of the parent plant. This rapid vegetative reproduction contributes to the plant's ability to colonize water bodies quickly.

Azolla (Fig. 3M)

Description: Azolla is a genus of small aquatic ferns that float on the surface of still or slow-moving waters. Commonly known as water ferns or mosquito ferns, Azolla species are characterized by their fronds, which have a feather-like appearance and are covered with fine hairs. The fronds can vary in color, including green, red, or brown. Azolla forms dense mats on the water's surface and can be found in ponds, lakes, and slow-flowing rivers. The fern is native to warm temperate and subtropical America **(Piñero-Rodríguez *et al.*, 2020)**.

Potential ecological impact: While Azolla is often used in controlled environments such as ornamental ponds and aquariums for its ability to cover the water surface and inhibit algae growth, it has the potential to cause ecological impacts when introduced to non-native environments. The dense mats formed by Azolla can shade the water and limit sunlight penetration, affecting the growth of submerged plants and altering the structure of aquatic habitats. This may have cascading effects on the biodiversity of the ecosystem. Azolla has the potential to become invasive in certain environments, particularly when introduced to non-native water bodies **(Piñero-Rodríguez *et al.*, 2020)**. The plant can spread rapidly, forming thick mats that cover the water surface. Furthermore, Azolla is known to be an efficient colonizer, and human activities, such as the unintentional release of Azolla from ornamental ponds or its transport on boats and equipment, can contribute to its spread. Once established, Azolla can be challenging to control due to its rapid vegetative reproduction.

Biology: Azolla reproduces both sexually and asexually but vegetative reproduction is more common **(Adhikari *et al.*, 2020)**. The plant has specialized structures called sporocarps that contain spores. These spores can develop into new plants when conditions are favorable. Azolla also reproduces vegetatively through branching and fragmentation. The ability to reproduce quickly through both sexual and vegetative methods contributes to its potential invasiveness.

Management control

These plants can form dense mats or clusters, alter water flow patterns, reduce light penetration, and modify substrate composition. Such changes can have cascading effects on the entire ecosystem, affecting the abundance and distribution of aquatic organisms, including fish, invertebrates, and microorganisms. Effective management of non-native invasive aquatic plants involves a multifaceted approach incorporating mechanical, biological, and chemical control strategies. Mechanical control methods involve the physical removal of invasive plants from water bodies. Techniques such as hand pulling, cutting, dredging, and the use of mechanical harvesters can be employed. Mechanical methods are often labor-intensive and may need repeated applications, but they can be essential for initial population reduction. A study emphasized the significance of mechanical removal in controlling invasive aquatic plants, demonstrating its efficacy in mitigating the spread and impact of such species.

Biological control involves the introduction of natural enemies, such as herbivorous insects or fish, to manage invasive plant populations. These biocontrol agents target the invasive plants, providing a sustainable and ecologically friendly solution. However, the success of biological control can vary depending on the specific interactions between the introduced agents and the target plants. A research illustrated the successful utilization of biological control agents in managing invasive aquatic plants, highlighting the importance of a careful selection process and thorough ecological assessments.

Chemical control employs herbicides to target and control invasive plants. It is often used in conjunction with other methods for integrated management. Careful consideration of herbicide choice, application methods, and potential environmental impacts is crucial. Studies like those have explored the effectiveness and environmental implications of various herbicides, aiding in the development of safer and more targeted chemical control strategies.

Integrated pest management, combining these control methods, has gained prominence due to its holistic and sustainable approach. By synergizing mechanical, biological, and chemical strategies, managers can optimize control efforts while minimizing the ecological impact. The effectiveness of integrated approaches in managing invasive aquatic plants emphasizes the need for adaptive strategies that consider the dynamic nature of ecosystems.

CONCLUSION

The checklist of non-native aquatic plants in the upstream, middle, and downstream sections of the Brantas River in East Java, Indonesia, provides a valuable snapshot of the current botanical composition in this critical water system. The data reveal the presence of several non-native invasive species across different locations, indicating the potential ecological challenges these plants pose to the native aquatic flora and the overall health of the river ecosystem. The widespread distribution of certain species, such as the water hyacinth and Azolla, suggests the need for targeted management strategies to mitigate their impact on water quality, habitat structure, and biodiversity. This checklist serves as a foundational resource for further research, aiding in the development of effective management plans and conservation efforts to preserve the ecological integrity of the Brantas River and other similar water bodies facing non-native invasive species challenges. Ongoing monitoring and research are crucial for understanding the dynamic nature of invasive plant populations and implementing adaptive management strategies to ensure the sustainability of aquatic ecosystems in the region.

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