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Spatiotemporal patterns of plastic entrapment by the invasive water hyacinth (*Pontederia crassipes* Mart.) in temperate South European Rivers

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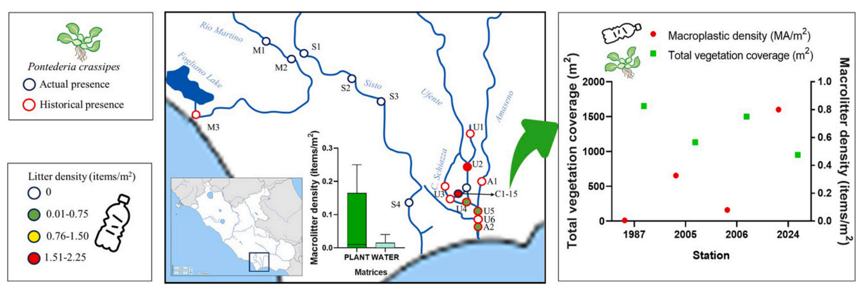
HIGHLIGHTS

- Two new records of *P. crassipes* found in central Italy's small canals.
- Water hyacinth traps up to 2.2 plastic items/m^2 in small temperate rivers.
- PET made up 55.1 % of plastic trapped by *P. crassipes* in riverine habitats.
- Historical plastic entrapment peaked in 2005 and 2024 at 1.7–2.2 items/m^2.

GRAPHICAL ABSTRACT



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ABSTRACT

The water hyacinth *Pontederia crassipes* Mart., native to Brazilian watercourses, has become among the most widespread and risky alien species globally. Introduced in Europe and Italy as an ornamental species, it has many detrimental effects on native biota and ecosystem functioning. However, it can filter water from contaminants, organic pollution and plastics. In central Italy, *P. crassipes* was first recorded in the Lazio region's Pontine plains in 1983. Given the neglect of the dispersal path, we (1) investigated the distribution along rivers in central Italy and (2) assessed plastic entrapment in small temperate rivers. Specifically, we compared recent field observations with historical records to evaluate trends in both species presence and associated macrolitter accumulation. Our findings reveal that *P. crassipes* spread in the Amaseno, Sisto, and Ufente rivers in agricultural land use, with historical invasions of *P. crassipes* in the Pontine area covering up to 20,000 m^2. Recent surveys identified two new records totaling 67.2 m^2 in small canal. Plastic entrapment ranged between 0.0 items/m^2 and 2.2 items/m^2. Precisely, the maximum plastic entrapment was found in "The small canal" (max: 2.2 items/m^2) and in a canal in the Ufente river (max: 1.7 items/m^2). Among polymers, PET was the dominant polymer (55.1 %), followed by EPS/PS and PO soft items (21.3 % and 16.9 %, respectively). Over the years, macrolitter density was highest in 2005 and 2024 (i.e., 1.7 and 2.2 items/m^2, respectively). These results might be pivotal to understanding future actions on species eradication as well as on clean-up activities using this alien species.

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1. Introduction

The water hyacinth Pontederia crassipes Mart., as a synonym of Eichhornia crassipes (Mart.) Solms, is among the most widespread and risky alien species globally (Coetzee et al., 2017; CABI, 2024, see Fig. S1). Water hyacinth inhabits South American rivers, and here it has an important role in the food web being food for consumers and filtering water from contaminants (Bengtson, 1983; Guo, 2017; Huynh et al., 2021). Being one of the most invasive species, water hyacinth has been listed in the top 100 *of the World's Worst Invasive Alien Species* according to the World Conservation Union (IUCN) (Lowe et al., 2000). From its native area, it has been largely introduced globally as ornamental species in Europe during the 20th century (Brundu et al., 2013; Guo, 2017). The species shows a global spread, especially in tropical and subtropical regions. As shown in Fig. S1 the species is widely distributed in the Asian country with strong concentrations in southeast Asia, as well as in Africa and regions of Australia. The European country shows scattered records especially in Mediterranean regions such as Italy and Spain. Particularly, *P. crassipes* was introduced from Trinidad in the United Kingdom between 1823 and 1825. In general, the species has been cultivated in many European gardens (in the UK, France, Netherlands, and Austria, Brundu et al., 2013; Brundu, 2015). In Italy, the introduction pathways and threats for *P. crassipes* were hypothesised by Brundu et al. (2013). Among the pathways of introduction and spread of the water hyacinth, some ways were presented, such as (1) introduction as an ornamental and (2) research and use for phytoremediation (Brundu et al., 2013).

In central Italy, the invasive status of *P. crassipes* has been studied in the Latium region by Anzalone (1983), Iberite and Pelliccioni (2010), and Brundu et al. (2013). Indeed, *P. crassipes* was first recorded in the Lazio region, in the Pontine plains, in 1983 (Anzalone 1983). Particularly, its populations were limited to small canals like the Rio Martino River. Afterwards, *P. crassipes* spread to other watercourses in the Pontine plains with a total surface of ~20,000 m^2 (about 16,300 m^2, data obtained from the 2004–2006 study campaign carried out by Mauro Iberite and Ilaria Pelliccioni). In small lentic canals, *P. crassipes* remain stuck as there are dams to control water for irrigation (Brundu et al., 2013). Every autumn the opening of canal dams allows small mats to flow seawards. Also, *P. crassipes* in this context is mechanically removed by the local authority responsible for water management (i.e. the *Consorzio di Bonifica di Latina*, Brundu et al., 2013).

As an alien species, many negative impacts and effects have been reported from *P. crassipes* to native freshwater biodiversity and ecosystems (Guo, 2017). *P. crassipes* success is associated with its very fast growth rates (Lowe et al., 2000), rapid clonal asexual reproduction and ability to adjust biomass allocation and phenotypic traits, and long-term seed viability (CABI, 2024). These traits give *P. crassipes* the ability to outcompete native flora more effectively than typical macrophytes (GISD, 2025). Indeed, water hyacinth presence can result in the decline of other native macrophytes (Mengistu et al., 2017) and also in the reduction of macroinvertebrates inhabiting macrophytes (Coetzee et al., 2017). These impacts strongly decrease ecosystem services such as oxygen depletion and water quality (Degaga, 2018). While the presence of native macrophytes positively influences the ecosystem functioning, like by retaining potentially polluting nutrients, the presence of *P. crassipes*' dense mats blocks sunlight and reduces water oxygen level, negatively affecting other aquatic organisms like native aquatic plants and fish (Omweno et al., 2024) Moreover, the spread of *P. crassipes* causes blockage of waterways hampering agriculture, fisheries, recreation and hydropower activities (Guo, 2017; Ayanda et al., 2020). The large mats of *P. crassipes* also allow more area as a ground for pests, parasites, and vectors, being a problem for fauna and human health (Tasew and Wendimagegnehu, 2022). Notwithstanding all these negative effects, water hyacinths can trap macrolitter in rivers acting as possible cleaners from rivers (Gallitelli and Scalici, 2024). Given the widespread issues provided by macrolitter on the biota, environment, and ecosystems (Napper and Thompson, 2018; Azevedo-Santos et al., 2021; Blettler and Mitchell, 2021; Cássio et al., 2022; Ouyang et al., 2022; Gallitelli and Scalici, 2023; Liro et al., 2023), detection of plastic retention as well as clean-up and mitigation actions are urgently needed.

Despite increasing recognition of aquatic vegetation as a potential sink for plastic litter, the role of invasive macrophytes in this process remains poorly understood. *P. crassipes*, one of the world's most invasive freshwater plants, is known to alter river hydrodynamics and trap floating debris, yet its contribution to macrolitter accumulation across different land use contexts has received limited scientific attention. This knowledge gap is particularly relevant in human-modified landscapes, where both invasive species and plastic pollution are widespread. This study aimed to (1) map the current distribution of *P. crassipes* in rivers of central Italy, and (2) evaluate its long-term role in plastic entrapment along a gradient of urbanization and land use intensity. To achieve this, we compared recent field observations with historical records to assess temporal trends in species presence and associated macrolitter accumulation.

We addressed the following testable hypotheses:

H1. Given the global spread of invasive species, we expect that *P. crassipes* distribution in central Italian rivers has expanded in recent years, particularly in areas influenced by urban or agricultural land use.

H2. Patches of *P. crassipes* are associated with higher plastic entrapment rates than uncolonized river reaches, with macrolitter accumulation increasing with the degree of upstream urbanization (i.e., land use).

H3. The degree of plastic entrapment is associated with the area of *P. crassipes* mats, which can lead to seasonal variations in macroplastic accumulation as macrophyte coverage expands during warmer months and contracts during cooler periods.

2. Material and methods

2.1. Study area

The study was conducted in the Agro Pontino area, located in the southern-western part of the Lazio region (Italy, Fig. 1). The waterways under study were the “Rio Martino”, the “Sisto” river, the “Ufente” river and the “Amaseno” river. The historical samplings were conducted in the summer period from 1987 and 2006. For the actual data, two sampling campaigns were set on 26th June and 6th July 2024. During both historical and recent campaigns, we investigated the same spots. This area is characterised by a Mediterranean climate with an annual average temperature of 16.1 °C (WorldData.info, WorldData, 2025). All the

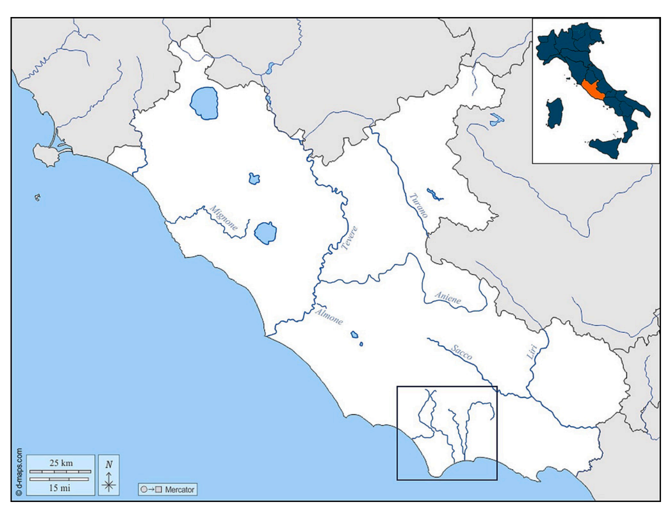

Fig. 1. Map of the study area focusing on the Lazio region and Agro Pontino area.
The map has been created on d-maps.com.

aforementioned watercourses are adjacent to highly fragmented areas as a result of agricultural activity and urbanization. Moreover, these watercourses show signs of modification, such as ramification, to create small channels that run along crops. The waterflow in these channels is visibly controlled by the presence of barriers which vertical movement allows to fill or empty the channel (as described in Brundu et al., 2013). In the study area, river discharge largely varies due to different dams that in spring-summer are closed and, consequently, stop the water flow with discharge around being zero, especially in the secondary channels. Concerning the watercourses in our study area, the values for the river discharge refer to the low-water period. River discharge varies from 1.3 m^3/s and 5.5 m^3/s (mean: 2.6 m^3/s) for the Ufente river in the 2006–2014 period in Ponte Ferraiolo (Cioffi and Giannini, 2025). River discharge for Sisto river reach 1329 l/s near Migliara 51 and for the Amaseno river about 2326 l/s near Ponte di Fossanova (Gazzetti et al., 2014). Despite some differences in river discharge, all these rivers were classified in first category of river discharge (<5 m^3/s) according to Tancioni et al. (2014).

The presence/absence of *P. crassipes* was observed in a total of 30 sites, 15 of which were located along a small channel derived by the ramification of the main Ufente river. This small channel does not appear to have a name so from now on we will refer to it as "The small canal". The existence of "The small canal" was randomly discovered during the investigations along the Ufente river and Schiazza Channel. It is 1.3 km long and it runs between the Ufente river and the Schiazza channel, the last being another ramification of the Ufente river. Of the remaining 15 sites, 6 were located along the Ufente river, 2 along the Amaseno river, 5 along the Sisto river and 2 along the Rio Martino (Fig. 1; Fig. S1). For each site, the presence/absence of *P. crassipes* was recorded. In addition, where non-native species was found, the number of individuals was counted or estimated, if the vegetation mat was too dense to distinguish the single individuals.

2.2. Macroplastic samplings

Overall, 5 rivers in central Italy were sampled to monitor *P. crassipes*. Precisely, the presence of *P. crassipes* was assessed at least at two sites per river, one upstream and one downstream. If *P. crassipes* was found, more detailed samplings were performed. Given that the species is found in freshwater bodies and does not survive in salt water (Ghoussein et al., 2023), samplings were conducted before estuaries.

Given the presence of *P. crassipes*, we tested if it could also trap litter in small watercourses - as it is known to trap litter in bigger rivers (Castrop et al., 2020; Schreyers et al., 2021; Guimarães et al., 2024). To do so, density for litter entrapment by aquatic vegetation is given by calculating the number of items divided by the area of the patch following the design in Gallitelli et al. (2021, 2024). Firstly, the plot area for vegetation was assessed and then plastics within the patch were counted and classified in polymer, size, and colours. In detail, microplastic items were classified according to OSPAR guideline and Gallitelli et al. (2024), with 7 categories on polymers (i.e., EPS/PS = expanded polystyrene/polystyrene, others, multilayer, PVC = polyvinyl chloride, PO soft = polyolefin soft, PO hard = polyolefin hard, and PET = polyethylene terephthalate). Plastic was sampled in river channel through visual census following protocols in Schreyers et al., 2021 and Gallitelli et al., 2024. As the proximity of the macrophyte beds to the riverbanks allowed close examination without the need to remove the material from the water, we were able to clearly determine the number of plastic items as well as identify their polymer, color and estimate their size. We considered plastics trapped in the surface, quantified with the already published and described methods, and plastics trapped thanks to the roots of plants. According to previous literature studies (Gallitelli and Scalici, 2024), we considered all plastics trapped by plants as trapped by roots or within plant mat (i.e., leaves and stems). Among the latter, we considered also floating plastics trapped by vegetation, standing on surficial water. To investigate macrolitter in aquatic vegetation, we adapted the protocol to assess macrolitter in riparian vegetation by Gallitelli et al. (2024). To quantify macroplastic density in the floating mats of vegetation, given that *P. crassipes* is an aquatic species, we considered plastics trapped in the surface and plastics trapped to the underwater roots of plants. Macrolitter counting did not include litter hidden beneath the plants mat, therefore bias of underestimation for macrolitter concentration may occur. Plot areas were calculated by using Google maps. Moreover, a control patch of the same area was considered to understand if vegetation can block plastics more than water. To set the control plot, we followed literature protocols found in Gallitelli et al. (2021). Regarding size of litter items, a scale size (i.e., 2.5–5 cm, 5–10 cm, 10–20 cm, 20–30 cm, 30–50 cm, >50 cm) has been used following González-Fernández et al. (2021) and Gallitelli and Scalici (2022). Moreover, the color of each litter item was noted following previous protocols (e.g., red, black, blue, white, transparent, gray, green, yellow, etc.).

To compare the presence of water hyacinth and its entrapment of plastics using historical data, we used data on water hyacinth 'presence. To extrapolate the number of historical macrolitter in water hyacinth, we used photos made during fieldwork in other research (i.e., Iberite and Pelliccioni, 2010). Data were detailed as archived photos have been made in same spots of the field investigation. Reliable data were extrapolated from photos as plastic was visible as well as the plant coverage in each area. Given that GPS locations and length of transects were available, we calculated macroplastic density as number of macroplastic items on the sampled area covered by water hyacinth (m^2). The same area covered by water of the watercourse was sampled to assess the difference of plastics between plant and water matrices. We then compared the number of macroplastic items with the area of *P. crassipes* mats to assess whether the two variables are positively correlated or not. Seasonal changes in mat size were then compared with changes in plastic accumulation to evaluate whether mat dynamics explain temporal variation in entrapment.

2.3. Data analysis

Before conducting statistical tests, the normality and homoscedastic of data distribution were checked. After checking, we used parametric tests when assumptions were confirmed by data distribution. To assess the difference of plastics between plant and water matrices, we used a *t*-test. To unveil if there are significant differences in polymer abundance over years, we tested it by using a Kruskal-Wallis test. If this test provides significant results, a Dunn post-hoc analysis among groups was conducted.

All the statistical analyses were carried out by using GraphPad software. All *p*-values were set with values lower than 0.05.

3. Results

3.1. New records of P. crassipes in Central Italy watercourses

During the samplings carried out in 2024 new records of *P. crassipes* were found as presented in Fig. 2 with previous historical records. The species was absent at all surveyed sites along the Amaseno (2 sites), Ufente (6 sites), and Rio Martino (2 sites) rivers. Along the Sisto River, *P. crassipes* was absent at three out of five sites; two upstream locations hosted small patches, with 2 individuals occupying 0.25 m^2 and 8 individuals occupying 1 m^2, respectively. The most abundant population was found along "The small canal," where 15 sites were surveyed over a 900 m stretch. *P. crassipes* was present at all these sites, covering a total area of 67.2 m^2, with 538 individuals observed (Table 1). No individuals were found in the remaining 400 m of the canal. In historical samplings, the mat of water hyacinth covered overall up to about 20,000 m^2, with a mean of 1128.8 m^2, minimum 500 m^2 and maximum 2800 m^2. Full site coordinates and presence/absence data are provided in Table S1 and Fig. S1, which include all the locations investigated.

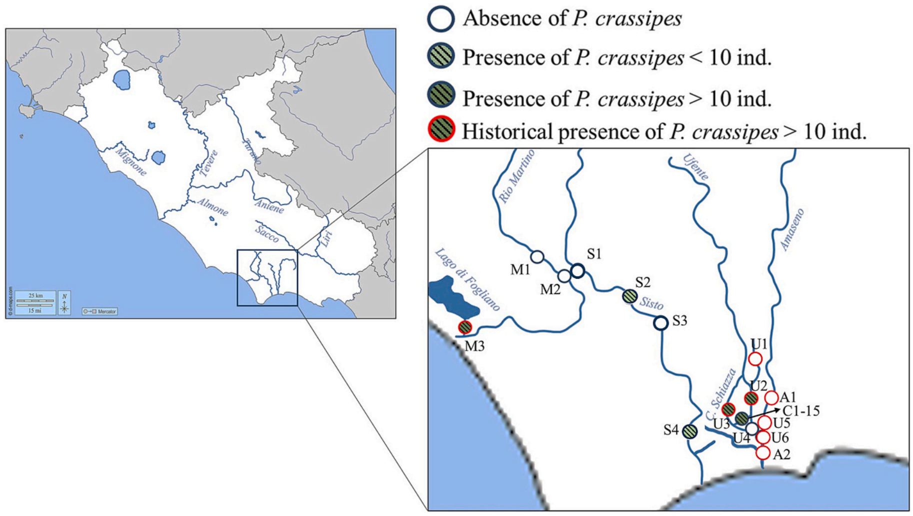

Fig. 2. Occurrence of *P. crassipes* in small watercourses of Lazio region. The striped shape in circles represents the presence of water hyacinth. The red dot represents the historical presence of water hyacinth.

Table 1
Summary of *Pontederia crassipes* presence/absence across all sampling sites. Distances are approximate from each river's mouth.

River	Site ID	Distance from mouth (km)	Presence of *P. crassipes*	No. of individuals
Amaseno	A1	3.8	Absent	0
	A2	5.3	Absent	0
Ufente	U1	11	Absent	0
	U2	9.3	Absent	0
	U3	5.8	Absent	0
	U4	4.0	Absent	0
	U5	3.8	Absent	0
	U6	3.6	Absent	0
Sisto	S1	31.8	Absent	0
	S2	25.5	Present	8
	S3	19.6	Absent	0
	S4	18	Present	2
	S5	9	Absent	0
Rio Martino	M1	18.3	Absent	0
	M2	12.3	Absent	0
	M3	1.1	Present	>10 ind.
The small canal	C1–C15	0.0–0.9	Present	538 ind.

3.2. Plastic entrapment by *P. crassipes* in watercourses

Water hyacinth was able to trap macrolitter items with a density ranging between 0.00 items/m^2 and 2.20 items/m^2 (Fig. S1). Precisely, few individuals were found in the Sisto and Rio Martino rivers, plastic entrapment by water hyacinth was zero. The plastic entrapment instead increased to 2.2 items/m^2 in "The small canal", with an average of 0.30 ± 0.54 items/m^2 (site 8 in Figs. 3, S1), and to 1.7 items/m^2 in a canal in the Ufente river (site 11 in Fig. 3). Among the most trapped polymers, plastic packaging and polystyrene box were observed (Fig. 4A). Furthermore, water hyacinth mat and tridimensionality can mainly trap litter, but also, although in rare occasions, its roots trapped packaging litter (Fig. 4B), highlighting the highest density of macrolitter found trapped in vegetation rather than in water (Fig. 5C). No significant differences were found between macrolitter in plants and water (t = 1213, df = 8, p = 0.26). Moreover, we found a correlation between the macrophyte patch area and the amount of retained plastics (r_s = 0.49, p = 0.006). During the years (Fig. 4D), macrolitter density was highest in 2005 and 2024 (i.e., 1.7 and 2.2 items/m^2, respectively).

Given the similar agricultural land use in the whole area, data analysis on land use related to plastic entrapment by vegetated patches does not provide significant results (r_s = −0.33, p = 0.53, Table S2). *P. crassipes* patches trap significantly more plastics in low-to-moderate flow conditions, where residence time is longer. In high-energy sites, vegetation may retain fewer plastics unless patch density and structure are high enough to resist flow.

Regarding the polymers of macrolitter trapped by water hyacinth, PET was the dominant polymer (55.1 %) followed by EPS/PS and PO soft items (21.3 % and 16.9 %, respectively, Fig. 5A). Over the years, PET was the most abundant polymer, with major peaks in 2005 and 2024 (Fig. 5B). Statistical tests confirmed those results (H' = 14.13, p = 0.03). Over the years, the patterns of macrolitter retention in water hyacinth increased from 1987 to 2024 (Fig. 5).

4. Discussions

In this study, we investigated the (1) distribution path of *P. crassipes* along rivers in Lazio region and (2) assessed the plastic entrapment in small temperate rivers. Our findings reveal that *P. crassipes* occurred in small canals and rivers spreading in the Amaseno, Sisto, and Ufente streams. Moreover, two new records of *P. crassipes* occurred in "The small canal". Furthermore, the plastic entrapment in small temperate rivers ranged between 0.0 items/m^2 and 2.2 items/m^2. Among polymers, PET was the dominant polymer followed by EPS/PS and PO soft items. Over the years, macrolitter density was highest in 2005 and 2024 (i.e., 1.7 and 2.2 items/m^2, respectively). Experimental studies show that long-term exposure to micro- and nanoplastics can change the freshwater invertebrate community composition, including declines in sensitive taxa over time (Redondo-Hasselerharm et al., 2020) and that plastics retained by macrophytes can act as exposure pathways for higher trophic levels via ingestion and additive release (Mateos-Cardenas et al., 2022). Thus, the entrapment of plastics in *P. crassipes* patches could have non-negligible ecological implications despite the relatively low densities observed if compared to the plastic entrapment in tropical rivers (Mekong and Amazon Rivers) with an accumulation mean of 8.0 MA items/m^2 of vegetation (see Gallitelli and Scalici, 2024).

Regarding the new records of *P. crassipes*, in contrast to H1, the overall distribution of *P. crassipes* can be described as scattered as no clear linear distribution pathway was observed. An interesting observation that came out of this investigation is that while along the Sisto river we only found two patches of two and eight individuals, the sites along "The small canal" showed a high number variability ranging from 4 to 120 individuals per site. The "The small canal" has been almost entirely covered by a mat of *P. crassipes*, with a density never observed in

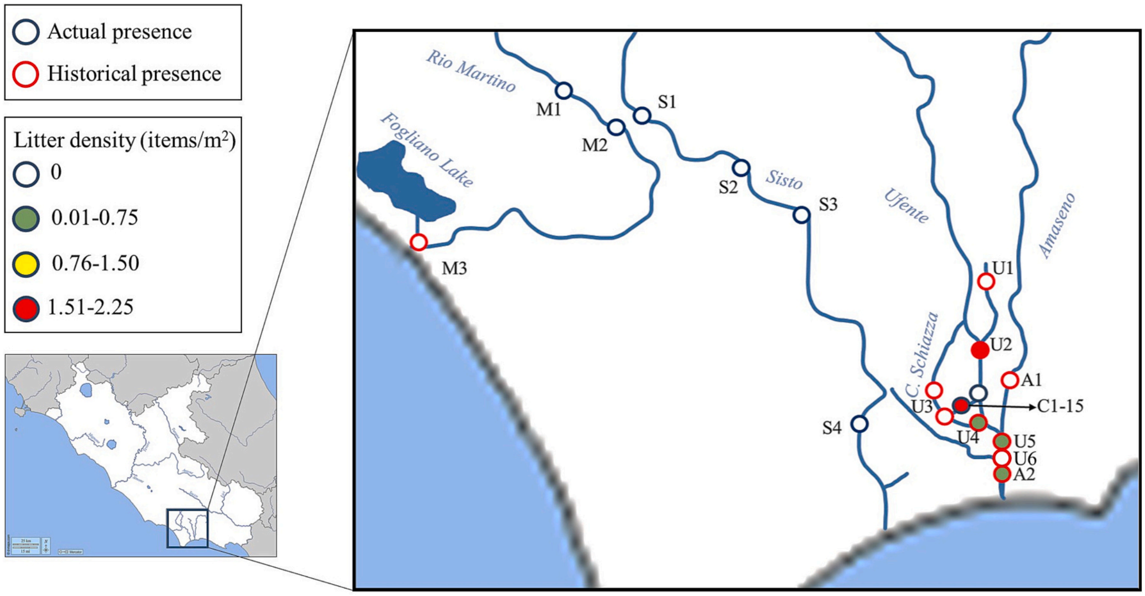

Fig. 3. Map showing water hyacinth trapping macrolitter in small watercourses. Litter density scored from 0.00 items/m^2 (white dots) to 2.25 items/m^2 (red dots). The red outline of dots represents the historical presence of the water hyacinth.

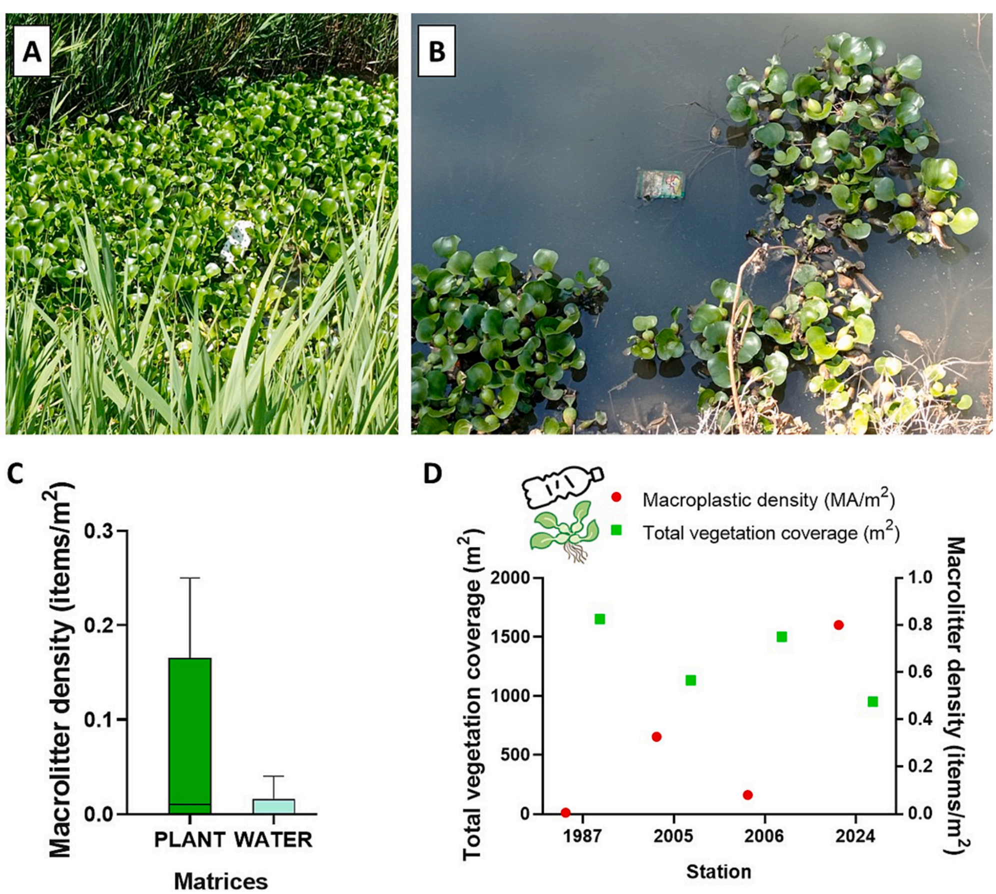

Fig. 4. (A) Polystyrene box trapped within *P. crassipes* mat. (B) Plastic packaging trapped by *P. crassipes*' root system. (C) Macroplastic density (items/m^2) shown for plastics in plants and water. (D) Total vegetation coverage along years and historical macrolitter entrapment by plants.

the other watercourses under investigation. The difference in density between the Sisto river and "The small canal" can be explained by the fact that its water flow, at the moment of the investigation, was blocked both upstream and downstream by artificial barriers so to keep *P. crassipes* from moving in the adjacent water courses (Schiazza channel and Ufente river). Moreover, we noticed that the water in "The small canal" was almost still and crops were present on both margins. These features may have enhanced *P. crassipes* growth thanks to the

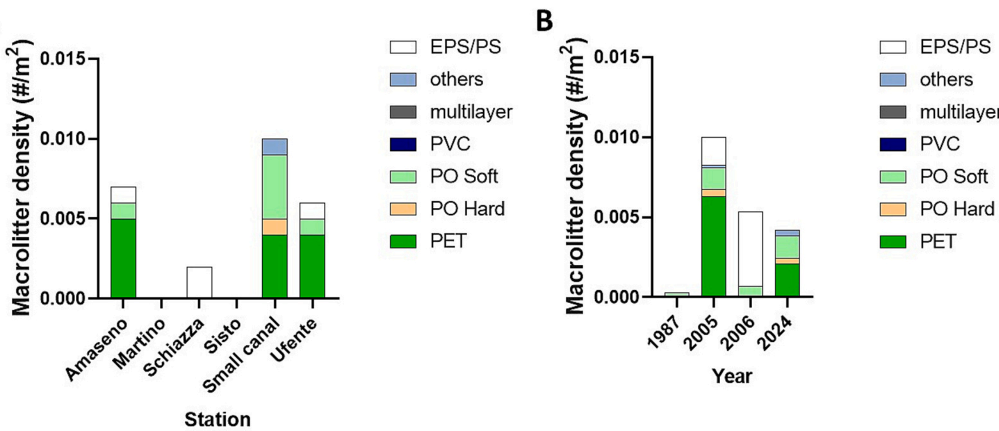

Fig. 5. Polymers of macrolitter density (items/m^2) found in water hyacinth in (A) rivers and (B) over the years. EPS/PS = expanded polystyrene/polystyrene, others, multilayer, PVC = polyvinyl chloride, PO = polyolefin, PET = polyethylene terephthalate.

accumulation of N and P derived from agricultural products, as it is known that in nutrient-rich sites its biomass can be eightfold compared with nutrient-poor sites (Coetzee et al., 2017).

Related to H2, plastic entrapment by *P. crassipes* likely varies with the spatial extent and biomass of the vegetative mats, as larger mats may provide greater surface area and turbulence for plastic interception (Gallitelli and Scalici, 2023). In this canal and rivers, the flow velocity is another critical factor as the lower flow rates favor retention of macrolitter, with rare high discharge events remobilising riverine macrolitter or transporting entire mats downstream. Precisely, turbulence and floods drive plastic remobilisation in channels and rivers with macroplastic density increasing with higher discharge levels as shown in field observations and indoor experiments (Valero et al., 2022; Owowenu et al., 2023). Another factor mediating plastic entrapment is the surrounding land use that, with urbanized or intensively farmed areas, may contribute to inputting more plastics into nearby canals (Dalu et al., 2025). In our study area, canals bordered by crops or roads may accumulate more packaging-related litter. In contrast to H2, although in our case we did not find any significant correlation between land use and macrolitter entrapment by vegetated patches, understanding these dynamics could help predict where plastic entrapment is most likely and guide localized interventions accordingly. Surprisingly, although the first discovery (Anzalone, 1983) of *P. crassipes* near the mouth of Rio Martino River in brackish water, we have not noticed the presence of *P. crassipes* in the estuary. Although water hyacinths can occur near estuary locations, however, the tolerance of *P. crassipes* to salinity is low and the species did not tolerate salinity higher than 5–15 ‰ according to laboratory studies (Mathiventhan et al., 2018; Ghoussein et al., 2023). Moreover, wilting and rapid death of plants are evident when exposed to salinities of 35 ‰, 25 ‰ and 15 ‰. Also, after almost a week, leaf scorch and petiole wilting were observed in plants exposed to low salinities (i.e., about 3 ‰ and 2 ‰). To long-term shock, death might occur after 22–25 days (Ghoussein et al., 2023).

For the first time, we highlighted historical plastic entrapment, based on scattered records over the past decades. This is one of the first studies to highlight the monitoring of plastic retention in rivers over years. In this way, future studies might address long-term monitoring to assess more precise and reliable results for plastic accumulation along rivers. Moreover, we also found that, over the years, macrolitter density was highest in 2005 and 2024. This could be due mostly to agricultural activities as the area is surrounded by agricultural land and crops. Given that agriculture might spread precise types of polymers (i.e, PO soft, foils, but also PET, PlasticsEurope, 2024), our results are in line with what literature pointed out for similar studies on macrolitter in rivers and riverbanks (Chowdhury et al., 2023). Regarding the polymers of macrolitter trapped by water hyacinth, we found that PET was the dominant polymer followed by EPS/PS and PO soft items. This finding is mostly in line with several studies in literature on plastic entrapment by plants (Gallitelli and Scalici, 2024). Precisely, aquatic plants from tropical rivers have seen to block PET as main polymer, sharing our same finding (Castrop et al., 2020; Schreyers et al., 2021; Gallitelli and Scalici, 2024). This common result draws an interesting pattern regarding plastic entrapment in different global rivers.

Concerning the vegetation mat area and density related to plastic entrapment, we confirmed H3 finding a correlation between the macrophyte bed area and the amount of retained plastics. This is a key finding as our finding is in line with similar studies, such as those conducted in the Amazon River. This means that higher macroplastic density is found in mats of vegetation characterised by higher density and area. Along rivers, *P. crassipes* and *P. rotundifolia* can trap macrolitter in tropical rivers (Mekong and Amazon Rivers) with an accumulation mean of 8.0 MA items/m^2 of vegetation (see Gallitelli and Scalici, 2024). In the Amazon River in Brazil, *Pontederia rotundifolia* accumulated the most plastic particles, showing 0.41 items/m^2 and 1.17 items/m^2 in rainy and dry seasons (Guimarães et al., 2024). Here, in central Italy rivers we found that *P. crassipes* trapped a maximum of 2.2 MA items/m^2. Thus, by finding about 3.6 times less than Mekong River and 10 times more than Amazon River, our results are partially in line with literature. However, although our *P. crassipes* patches were locally fixed to the substrate due to low water height, *P. crassipes* in the Mekong and Amazon Rivers showed a high transport value. This means that this invasive species could act as a good trapper of macrolitter in both lotic and lentic rivers, independently from the river discharge. More in detail, of great interest is the different behaviour of the species in tropical and temperate rivers, the species floats and follows the river current. Moreover, when accumulating, the species form large mats that stop the river current and navigation. This results in serious threats to the riverine ecosystems as these large mats prevent oxygen from being exchanged and therefore cause anoxia. Consequently, the lack of oxygen causes riverine biota sublethal and lethal effects (Degaga, 2018). Another issue is provided by entrapment of macro and microplastics in the roots of *P. crassipes* in Orontes River (Turkey) (Kılıç and Yücel, 2024). This could be a potential threat as the plant may move plastic particles to other river habitats and to the sea. In the end, all this process could lead to poor river water quality and bad status, losing important ecosystem services provided by water (i.e., irrigation for crops, drinking water, animals drinking, etc). To sum up, the presence of *P. crassipes* mats and the plastics entrapped therein might serve as a practical bioindicator for plastic accumulation in small and medium-sized rivers. Monitoring mat density and composition over time can provide early warnings systems for the increase of plastic pollution. The management and targeted removal of mats in specific canals could be performed with clean-up efforts to maximize plastic collection and mitigation in urban or agricultural watersheds.

Among limitations of this study, we should claim that the mat of *P. crassipes* is too dense in certain sites that can probably cover macrolitter leading to an underestimation of counting. Despite a clear rising trend in plastic presence from 1987 to 2024, the annual input and washout rates of plastics for these rivers remain unknown. Consequently, the observed quantity of plastics retained by macrophytes may be subject to significant annual variability driven by fluctuating input loads. A major challenge for effective plastic mitigation remains unraveling the total plastic input into a river system and identifying the specific accumulation zones throughout the watershed. Given that Italy's watercourses showed the highest number of alien aquatic species ($n = 34$, Hussner, 2012), the impact on native ecosystems is high, but also the economic costs. Indeed, the economic costs of *P. crassipes* come from their impacts and their management costs, as well as their impacts on ecosystem services which are very hard to quantify (Guo, 2017; Lesieur et al., 2023). We should consider that one hectare of *P. crassipes* may contain more than two million individual plants with a total wet weight of over 300 t (Center and Spencer, 1981), that is 10 individuals per square meters, more or less the same amount we observed in certain sites. To solve the spread of invasion and maintain a good status of watercourses, prioritizing environmentally invasive weeds could be pivotal. This could be achieved by (1) eradication and (2) classical biological control (Lesieur et al., 2023). To check water hyacinth spread along watercourses, future research could use tools such as satellites and drones (see Ghiani et al., 2023). Future perspectives to control and monitor the occurrence and spread of *P. crassipes* would be helped by satellites and drones to have further data (Ghiani et al., 2023). Prioritizing strict management for *P. crassipes* should be essential to monitor and prevent (i.e., early detection) its spread in global watercourses, affecting the important resource of water (EASIN, 2018). Regarding the ecological and management implications of *P. crassipes* as a plastic retainer, future research should go beyond identifying the problems and consider management strategies that reconcile plant control with its potential ecological role, such as macroplastic retention. When considered over years, our results suggest an increasing occurrence of plastic associated with *P. crassipes*, with macrolitter densities peaking in 2005 (0.3 items/m^2 in all watercourses and 1.7 items/m^2 in the small canal) and again in 2024 (0.8 items/m^2 in all watercourses and 2.2 items/m^2 in the small canal). These peaking of plastic retention may be due to the low flow of these small sized rivers (see Tancioni et al., 2014; Cioffi and Giannini, 2025) amplified by low precipitation rates and drought. This pattern may indicate a progressive accumulation of plastics in invaded habitats, underscoring the growing role of *P. crassipes* mats as retention hotspots in these freshwater ecosystems. For instance, approaches like selective removal, use of directional barriers, or floating collection systems could be explored as ways to enhance plastic capture while preventing the excessive spread of the species. This would strengthen the applied relevance of the study and offer pathways for practical action. In addition to this, we should consider that being a plastic retainer can have some limitations. This study corroborates the hypothesis that aquatic plants may efficiently trap macroplastic litter, as already shown in literature (Gallitelli and Scalici, 2024; Guimarães et al., 2024). Given this potentiality to trap plastics, on the one hand, plastic entrapment by aquatic plants may be an opportunity for future operation of plastic removal to mitigate plastic pollution. On the other hand, the use of macrophytes as barriers for plastic retention may have a potential negative effect on biodiversity and ecosystems. This might be mostly because of the biodiversity inhabiting macrophyte beds that can be contaminated by macro and microplastics by the release of toxic additives and absorbed pollutant and leading to their transfer through the freshwater food chain (Mateos-Cardenas et al., 2022). Since several studies showed that ingestion of macro and microplastics is a major threat for biodiversity (Azevedo-Santos et al., 2021; Blettler and Mitchell, 2021), therefore it is pivotal to highlight and consider the potential risks that plastic presence may trigger for aquatic biota and even the plants themselves.

5. Conclusions

In our research, we reported new records for this alien species in central Italy rivers, providing also the first field evidence of historical and present plastic entrapment by water hyacinth in small rivers. *P. crassipes* has recently started invading the Italian freshwater watercourses. These new findings provide further evidence of *P. crassipes* spreading in our territory with future consequences and impact on our biodiversity and ecosystems. Notwithstanding these impacts, given that the species do not survive in seawater and considering its ability to trap litter in small rivers, would it be possible to use the species to trap macrolitter in watercourses? To monitor and mitigate *P. crassipes* spread, monitoring activities and specific management plans (strictly related to plastic pollution mitigation) are urgently needed.

CRediT authorship contribution statement

L. Gallitelli: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **C. Marcellucci:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Investigation, Formal analysis, Data curation. **M. Iberite:** Writing – review & editing, Visualization, Validation, Software, Investigation, Data curation. **M. Scalici:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition.

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Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2025.180945.

Data availability

Data are available in the manuscript and supplementary materials.

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