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Article

The Role of Estuarine Wetlands (Saltmarshes) in Sediment Microplastics Retention

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Abstract: Concerns regarding plastic pollution, especially microplastics, have increased, as they can be present in different environmental compartments, including estuarine areas and saltmarshes. Although saltmarshes are highly vulnerable to different human activities and pressures, they have the ability to trap/retain contaminants in their vegetated sediments. However, there is still little information regarding the role of saltmarshes in microplastic retention. Thus, the present study aims to investigate the capability of an estuarine saltmarsh to trap microplastics by comparing microplastic concentrations in vegetated (saltmarsh) and non-vegetated sediments. Microplastic content from sediment (vegetated and non-vegetated) samples collected at different sampling sites in Lima River estuary was estimated using previously optimised extraction protocols, and the observed particles were then characterised accordingly to their size, colour, shape, and polymer (by FTIR). Water samples were also collected and analysed for their microplastics content to complement MPs characterisation within the estuarine area. Microplastics were detected in all sediment samples, with fibres being the most common type of microplastic found, followed by fragments/particles. Overall, vegetated sediments, especially those of saltmarsh species *Juncus maritimus*, presented a higher number of plastic items. These results indicated that microplastics tend to be trapped in vegetated sediments, supporting the fact that saltmarshes have a significant influence on the transport, distribution, and accumulation of MPs in estuarine areas.

Keywords: estuaries; microplastics; saltmarshes; sediments

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1. Introduction

The production and use of plastic has increased worldwide since 1950 [1]. However, the durability of plastic has turned into one of the most relevant and persistent pollution problems in the world [2]. In fact, plastic is now ubiquitous in aquatic environments, including in coastal and estuarine regions. The continuous production of new plastic items, along with poor waste management practices, has led to a continuous accumulation of plastics in different environments. Plastic debris were classified by the United Nations Environmental Programme in 2014 [3] as an emerging environmental issue, taking into consideration the harm it inflicts on organisms and on organism's habitats. Moreover, the impacts are not only environmental, but also economic and social, affecting marine biodiversity and ecosystem health [1]. Of particular concern are microplastics (MPs), which have been found in different aquatic environments and can compromise ecosystem health [4]. MPs are commonly defined as small plastic particles with a size smaller than

5 mm. These particles can result from the fragmentation of plastic debris due to diverse physical, chemical, and biological processes [5], the so-called secondary MPs. However, MPs can also be purposely produced at that size by the plastic industry or for incorporation, for instance, in cosmetic products [6], being called primary MPs. MPs differ in their types, shapes, colours, sizes, and densities, and their characteristics are strongly related to their source, fate, and toxicity.

Apart from being one of the most productive temperate ecosystems, estuaries have a very high ecological value due to all the services and benefits they provide for society. Nevertheless, estuarine areas and their saltmarshes have been subjected to several human-related stressors as a consequence of urbanization, industrialization, inadequate wastewater treatment, intensive agriculture, maritime activities, etc. [7]. Moreover, estuaries have been systematically contaminated by litter, and mainly plastic [8]. In fact, due to their natural features, estuaries have been reported to be one of the zones in which MPs tend to accumulate [7] and there have been several reports of MPs contamination in estuaries located in different world regions, both in the water column and in bottom sediments [9]. MPs can be detected in high amounts in aquatic media, but sediment has been shown to be a significant sink for these particles as well [10]. Studies have reported that MPs levels in estuarine waters greatly vary from values close to zero (not detectable) to more than 1000 MPs per m^3 depending on the world region being surveyed [9]. A similar trend has been observed for estuarine sediments, with MPs concentrations varying from non-detected to more than 4000 items per kg [9,11].

It is known that the majority of marine MPs pollution comes from land-based sources [8,9] and strategies are needed to tackle this problem. As mentioned, studies have shown that rivers and estuaries can be significant MPs sources, but sediments can be also MPs sinks and contribute to their retention, preventing MPs from reaching coastal areas and the ocean. However, the role of estuaries in MP transport is still not fully known. In fact, MPs characteristics (e.g., shape, size, density, polymer type) influence their environmental behaviour. For instance, smaller and lighter particles can travel longer distances, while higher and heavier particles can be more easily retained in sediments, but both vertical and horizontal transport processes can affect this, as well as the shape of MPs [9]. Moreover, MPs polymeric composition can also affect its sinking velocity and distribution [9,12,13]. Furthermore, not only MPs characteristics, but the characteristics of the environment itself (including climatic variables, physical characteristics, and anthropogenic pollutants loads) will also affect MPs transport and distribution [9,14].

Vegetated areas, such as estuarine saltmarshes, can also affect the dynamic of MPs, significantly changing MPs abundance in estuarine ecosystems [15]. Vegetated sediments seem to be a suitable sediment type for pollutant retention compared to bare soil, thanks to the presence of dense root and rhizomes systems [16]. Plant roots and rhizomes can act as a net and/or promote the retention of thin sediments, leading to a decrease in water flow and turbulence in these areas, which consequently leads to the retention/accumulation of pollutants, including trapping MPs. A few studies have reported MPs in saltmarsh sediment from around the world [8,17–19], also indicating that MPs contamination in wetlands is directly linked to human activities [20] and that plastic debris were in much higher amounts in these sediments than in the water column [21]. However, the values were highly variable, from non-detected to 3000 items per kg of sediment (dry weight), and between non-detected to 75,000 items per m^2 (area of sediment). A few recent studies on mangroves have shown that MPs retention also depends on plant species and vegetation density (e.g., [12,22]); however, to our knowledge, information on saltmarsh plants is still lacking and the role of estuarine saltmarshes on MPs retention and/or distribution needs more research.

A high content of MPs has been reported in Portuguese coastal areas [23], with higher amounts in the North, Centre, and Lisbon regions [24]. For instance, the presence of MPs has been reported in coastal and estuarine waters of NW Portugal [25]. However, to our knowledge, the role of saltmarshes in MPs retention in these areas has still not been studied.

Therefore, this study aimed to assess MPs pollution in saltmarsh sediments, as well as to compare the amounts of MPs present in zones with and without plants. As such, the Lima estuary (North Portugal) was used as a case study, and sediments colonised by different saltmarsh plant species were sampled to assess their role as MPs retainers and to increase knowledge on MPs transport and distribution in vegetated estuarine areas.

2. Materials and Methods

2.1. Sampling and Samples Preservation

The Lima estuarine saltmarsh was used as a case study. The Lima estuary has high ecological relevance [26], including important and sensitive areas, such as the saltmarsh, but it has been vulnerable to a number of anthropogenic disturbances, resulting in habitat loss [27]. Furthermore, the Lima estuary receives diffuse pollution from agriculture activities and in terms of industrial waste discharge, and can be impacted by the maintenance of a navigation channel through regular dredging and the presence of a commercial harbour at its end [28].

The Lima estuary is located in the north-west of Portugal and it extends for approximately 20 km upstream of the river mouth, comprising a total estuarine area of 6 km^2. Three intertidal saltmarsh sites were selected for sediment collection (Figure 1):

(1) Sra. das Areias (site A)—located in the south margin of the lower section of the Lima estuary. A small open water reservoir drains into this sampling station (A2);
(2) Salinas (site B)—located in the north margin of the middle estuary. There is a freshwater stream close by, Ribeira de Portuzelo;
(3) Canoagem (site C)—located in the south margin of the middle estuary.

Figure 1. (**A**) Localization of the Lima estuary within the Iberian Peninsula and (**B**) the Lima estuary with sampling locations for vegetated and non-vegetated sediments: Sra das Areias (site A) and Salinas (site B), both colonized by *J. maritimus* and *P. australis;* and Canoagem (site C) colonized by *J. maritimus* and *S. maritima* and locations for water collection: upstream the saltmarsh (C1 and C2), within the saltmarsh (S1, S2, S3, and S4), downstream the saltmarsh (A1) and possible pollutants sources (A2 (open water reservoir); B1 and B2 (freshwater stream)).

During high tide, all sites are flooded, and during low tide the area is almost dried. Two sampling campaigns were carried out at low tide, in November 2021 (autumn) and February 2022 (winter). At each site, both vegetated and non-vegetated sediments were collected with a metallic shovel and samples were stored in aluminium foil for further laboratorial procedures.

Non-vegetated sediment was collected within 50 m from the respective vegetated sediment. Vegetated sediments samples were taken from the sediment in contact with plants' belowground tissues. Depending on the sites, plant species included *Juncus maritimus*, *Phragmites australis*, and *Spartina maritima* (Figure 1). *J. maritimus* is a perennial macrophyte that lives in permanently or periodically wet habitats, such as saltmarshes. The plant is differentiated into an underground long and thick horizontal rhizome with roots growing downwards from it, and with the stem of the plant growing upwards [29]. *P. australis* is an emergent aquatic and wetland perennial plant. Its belowground system is composed of a horizontal rhizome, which aims to extend the size of the plant, and a vertical rhizome that gives rise to annual stems. The rhizome contains nodules from which roots grow downwards and stems grow upwards [30]. *S. maritima* is a macrophyte from the Poaceae family that lives in high salinity and highly humid loamy soils covered during high tides. This rhizomatous grass specie is characterized for having a continuous but slow growth, and a root system similar to the one of *P. australis*. A total of 18 sediment samples were collected, 9 in each season with the following distribution:

(1) Sra. das Areias (Site B): 3 samples (non-vegetated; *J. maritimus*; *P. australis*)
(2) Salinas (Site B): 3 samples (non-vegetated; *J. maritimus*; *P. australis*)
(3) Canoagem (Site C): 3 samples (non-vegetated; *J. maritimus*; *S. maritima*)

In February 2022, water samples were also collected at different sites along the saltmarsh and at some possible pollutant sources (Figure 1). Water samples were collected in 1 L glass bottles previously decontaminated (thoroughly washed with deionised water and ethanol).

Only one sample per sampling point was collected in each sampling campaign.

In the laboratory, sediment samples were lyophilized and kept wrapped in aluminium foil in dark conditions until they were processed for MPs analysis. Water samples were filtered through 0.45 μm cellulose filters, with the filters being left to dry at room temperature in the dark until they were processed for MPs analysis.

2.2. MPs Analysis

Specific laboratorial procedures were conducted to avoid and control contamination by aerial MPs, namely: (i) all the material was previously washed with deionized water and ethanol to avoid MP contamination; (ii) 100% cotton grey laboratory coats and nitrile gloves were always used during the procedures; and (iii) all the steps were carefully followed so as not to lose any possible MPs in any step by carefully rinsing all the material. Finally, controls (with deionised water) were carried out to check any airborne contamination of MPs by doing the same procedure as with the samples.

2.2.1. MPs Extraction

Initially lyophilized sediments were sieved through a 2-mm mesh. Residues in the mesh were visually inspected and any MP detected was removed with metallic tweezers and individually placed in a glass Petri dish for characterisation.

MPs extraction from the sieved sediment samples was carried out following an optimised protocol [31], adapting it to the type of sediment. Briefly, a known mass of sediment (ca. 20 g) was initially re-suspended in a saturated NaCl solution. Afterwards, the floating layer was separated and subjected to subsequent digestions with a 30% H_2O_2 solution and 0.05 M Fe(II) solution. The mass of the sediment used (ca. 20 g) was selected because a higher amount would cause a violent reaction during the digestion of the samples due to the high content of organic matter (>5%) in the sediments, which could lead to the loss of particles as well as affect their integrity. This digestion step was followed by a density separation step with saturated NaCl solution. After discarding the bottom part, the supernatant was filtered through a 0.45 μm pore size cellulose filter. The filter was then placed into a glass Petri dish and left to dry for later MPs characterisation. It should be noted that some MPs polymers are denser (e.g., PET) and NaCl might not be the most suitable reagent for density separation. Moreover, some organic matter aggregates might trap MPs in sediments. Although the protocol optimised [31] has shown good recoveries (>80%) for different types of MPs polymers, including for denser ones, and for sediments with different amounts of organic matter, some MPs underestimation might occur. However, as both vegetated and non-vegetated sediment are subjected to the same MPs extraction protocol, one can consider their comparison.

For MPs extraction from the water samples, a methodology developed by [32] was used, consisting also of digestion with a 30% H_2O_2 solution and 0.05 M Fe (II) solution, followed by a density separation step with saturated NaCl solution and filtration through a 45 μm pore size cellulose filter, which was left to dry for later MPs characterisation.

2.2.2. MPs Characterisation

The characterisation of MPs in the filters (both from water and sediment samples) was carried out using a Leica EZ4 W stereomicroscope (Wetzlar, Germany) connected to a computer with LAS X Office 1.4.4 software, to register the colour, size, and shape of each particle found. First, whenever a possible MP was found, an image of it was taken and saved. Images were then analysed using ImageJ software (bundled with Java 8).

For the shape of the particles, three forms were considered: fibres, particles, and fragments. Fibres were further characterised by their length (in mm) using the ImageJ software segmented line tool. Particles and fragments were further characterised by their area, using the ImageJ software's polygon tool. MPs were considered particles when they presented a sphere shape and fragment when they presented an irregular, non-specific, shape.

A subsample of the most representative MPs in each sediment sample was selected for polymer identification. For that, MPs were collected from the filters with metallic tweezers and individually placed in a glass Petri dish for characterisation by Fourier-transform infrared spectroscopy (FTIR). Since only MPs of suitable sizes and amounts collected from the filter and above the detection limit of the equipment could be selected, no MPs from water samples were characterised in terms of polymer type. Polymer spectra were registered in a PerkinElmer (Waltham, MA, USA) FT-IR Spectrum 2 instrument coupled with attenuated total reflectance (ATR).

2.3. Data Analysis

For the sediment samples, the concentration of MPs was expressed as the number of items (MPs) per kg of dry sediment; and for estuarine water samples, as the number of items (MPs) per L of water.

Each obtained spectra from FTIR was compared with reference library spectra; matches with confidence levels of >75% were accepted.

3. Results

3.1. MPs in Estuarine Sediments

In the sediment samples collected in November 2021, fibres were the most common type of MPs found, followed by fragments, and a small number of particles (Figure 2A). Fibres were present in all of the nine samples collected, whereas eight samples contained fragments and only four had particles. Black MPs, the most frequent colour, were found in all kinds of sediments (Figure 2B), followed by blue and red MPs, present in eight out of nine samples. The least frequent colour was white, being only present in *J. maritimus* sediments from the Sra. das Areias and Salinas sampling stations. In general, most fibres had a length lower than 1 mm or between 1 and 3 mm (Figure 2C), the most common ranges of size found. Almost all particles and fragments had an average area between 0.001

and 0.1 mm^2 (Figure 2D). Examples of MPs observed in the sediment samples are shown in Supplementary Material (Figure S1).

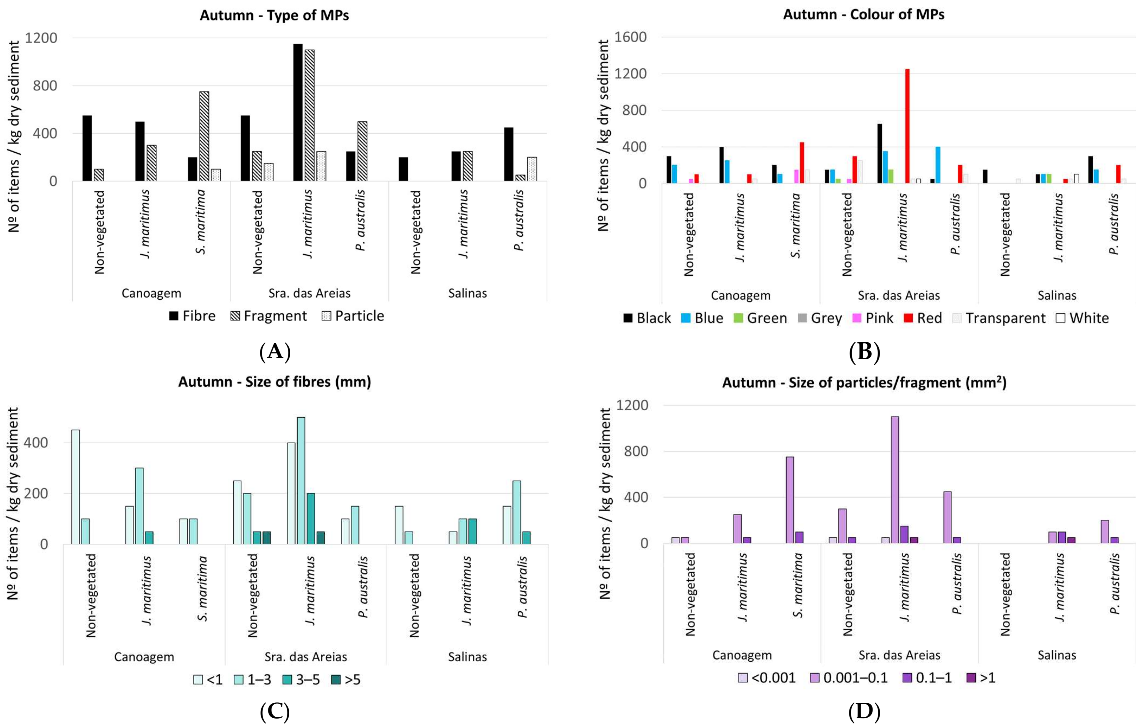

Figure 2. MPs content (number of items per kg of analysed dry sediment) and characterization from sediments collected in autumn (November 2021), discriminated by: (**A**) type of MPs; (**B**) colour of MPs; (**C**) size of fibres (mm); (**D**) size of particles and fragments (mm^2).

In general, for this sampling campaign, in terms of sites sampled, Sra. das Areias had the highest MPs concentrations and there was a general tendency for higher MPs content in vegetated sediments than non-vegetated ones (Figure 3). The type of MPs more frequent in non-vegetated sediments was fibre, whereas, for vegetated samples, particle/fragment abundance was, in general, similar to fibre (Figure 2).

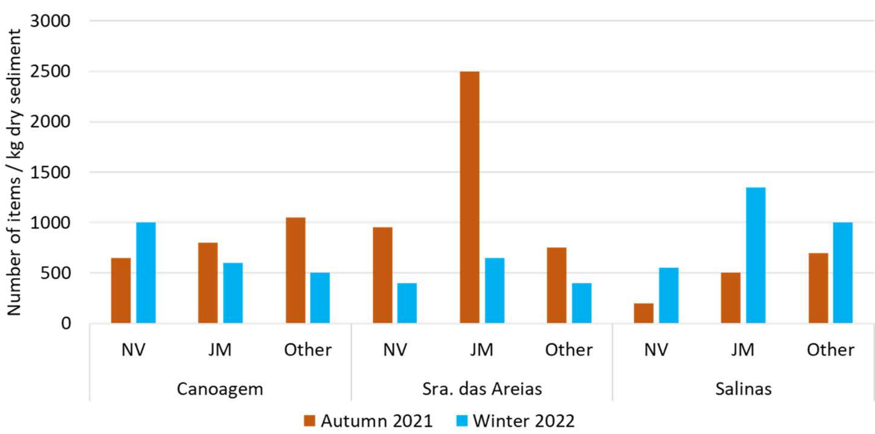

Figure 3. MP abundance in the Lima estuary sediments per sampling site (Canoagem, Sra. Areias, and Salinas, locations in Figure 1) and type of sediment (non-vegetated (NV) and vegetated by *Juncus maritimus* (JM) or by *Phragmites australis* (Other in Sra. das Areias and Salinas) or *Spartina maritima* (Other in Canoagem) in different sampling campaigns (autumn (November) 2021 and winter (February) 2022).

For the winter sampling campaign (February 2022), in general, fibres were again the most abundant type of MPs (Figure 4A). Fibres and particles were present in all of the nine samples collected, whereas eight contained fragments. Blue and red MPs could be found in all sediment samples (Figure 4B), being the most frequent colours, followed by black, which was present in eight samples. The least frequent colours were green, pink, and white. In general, most fibres had a length lower than 1 mm or between 1 and 3 mm (Figure 4C). Almost all particles and fragments had an average area between 0.001 and 0.1 mm^2 (Figure 4D).

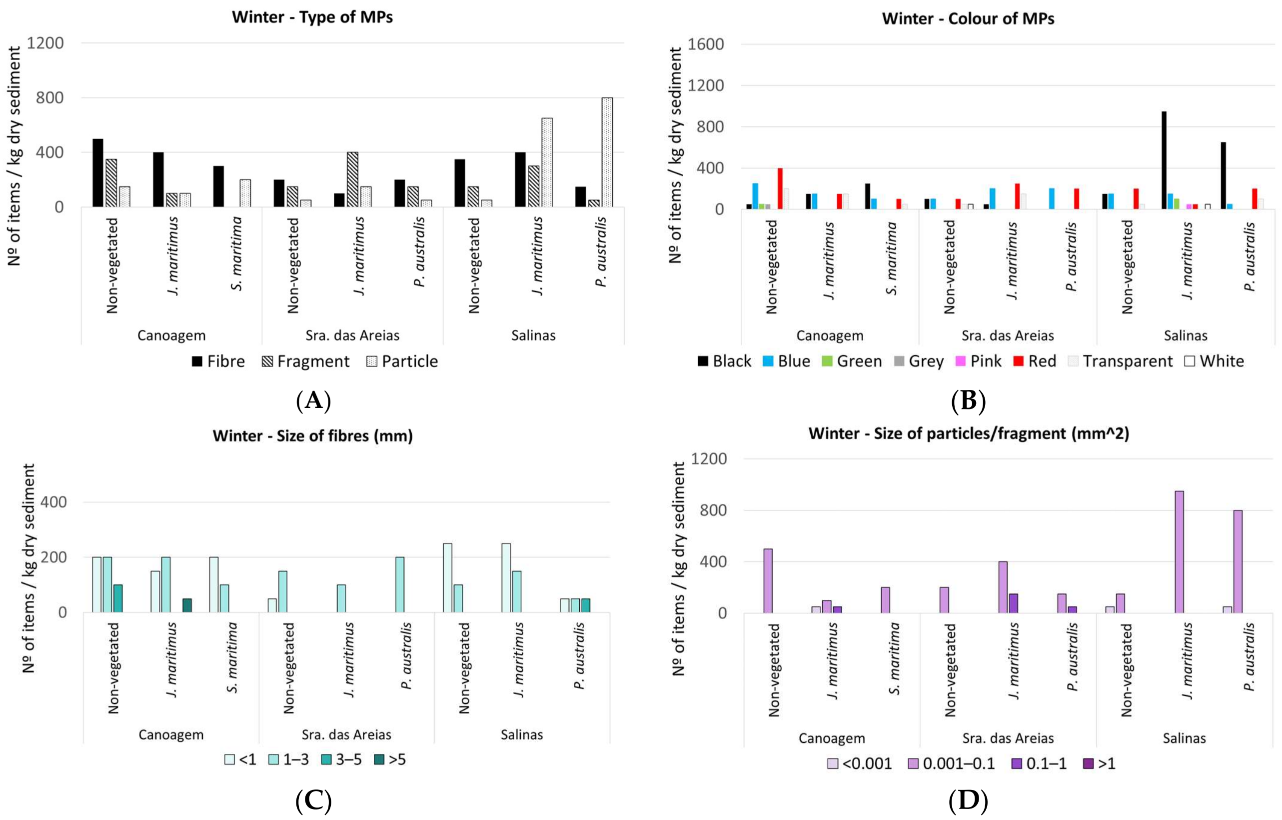

Figure 4. MPs content (number of items per kg of analysed dry sediment) and characterization from sediments collected in winter (February 2022), discriminated by: (**A**) Type of MPs; (**B**) Colour of MPs; (**C**) Size of fibres (mm); (**D**) Size of particles and fragments (mm^2).

In this sampling campaign, sediment samples from the Salinas site had, in general, the highest MPs concentrations (Figure 3). Vegetated sediments again had a higher number of MPs; however, only at two sites (Salinas and Sra. das Areias). At the Canoagem site, non-vegetated sediments had a higher number of MPs. Again, the type of MPs more frequent in non-vegetated sediments was fibre, followed by fragments, while for vegetated samples, all types of MPs were present in almost the same proportion (Figure 4).

Comparing seasonal campaigns, sediment samples from the autumn season (November 2021) had a higher total number of MPs than the ones from the winter season (February 2022) (Figure 3).

The identification of the polymer type in several of the MPs found in sediments (mainly fragments) is presented in Table 1. Only a few particles (ca. 50 particles, 10–15% of the particles found) were possible to analyse by FTIR as the technique requires a minimum size and amount of the particles to be processed, and no other analytical tools were available to evaluate particle polymers. The results indicated that the MPs selected were mostly of common polymers, such as polyethylene (PE), polypropylene (PP), and polystyrene (PS). PE was the most common one, followed by PS.

Table 1. Polymer type, polyethylene (PE), polypropylene (PP), and polystyrene (PS) of the MPs found in sediment samples (vegetated and non-vegetated) collected in autumn (November 2021) and in winter (February 2022) at the three sampling sites (Canoagem, Sra. Areias, and Salinas, locations in Figure 1). * not possible to characterise MPs polymers due to their low size and/or amount.

	Sediment Samples								
	Canoagem			***Sra. Das Areias***			***Salinas***		
	Non-Vegetated	**Vegetated *Juncus maritimus***	**Vegetated *Spartina maritima***	**Non-Vegetated**	**Vegetated *Juncus maritimus***	**Vegetated *Phragmites australis***	**Non-Vegetated**	**Vegetated *Juncus maritimus***	**Vegetated *Phragmites australis***
November 2021 (autumn sampling)	2 Fragments red and pink PE	2 Fragments blue PS 1 Fibre blue – PS	3 Fragments transparent and blue PE	*	1 Fragment blue PP 1 Fragment white PS	1 Fragment blue – PP 1 Fragment blue PE	*	2 Fibres black and blue PE 1 Fragment white PS	2 Fragments blue and transparent PE 1 Fibre Blue PS
February 2022 (winter sampling)	1 Fragment transparent PE	2 Fragments transparent and blue PS 1 Fibre Blue PS	3 Fragments transparent and white PS	*	2 Fragments red and blue PE 1 Fragment transparent PP	1 Fragment red PE 1 Fibre red PE	2 Fragments white and transparent PE	2 Fragments transparent PE 1 Fragment green PP	*

3.2. MPs in Estuarine Waters

Regarding water samples (Figure 5), the samples within the saltmarsh (S1–S4) showed relatively higher MPs concentration than the remaining samples. Additionally, the lowest MPs concentration was observed in water from the potential contamination sources (A2, B1, and B2). Considerably lower quantities of MPs were observed at S3 compared with the rest of the S samples, indicating that MPs concentration in the saltmarsh area spatially varied.

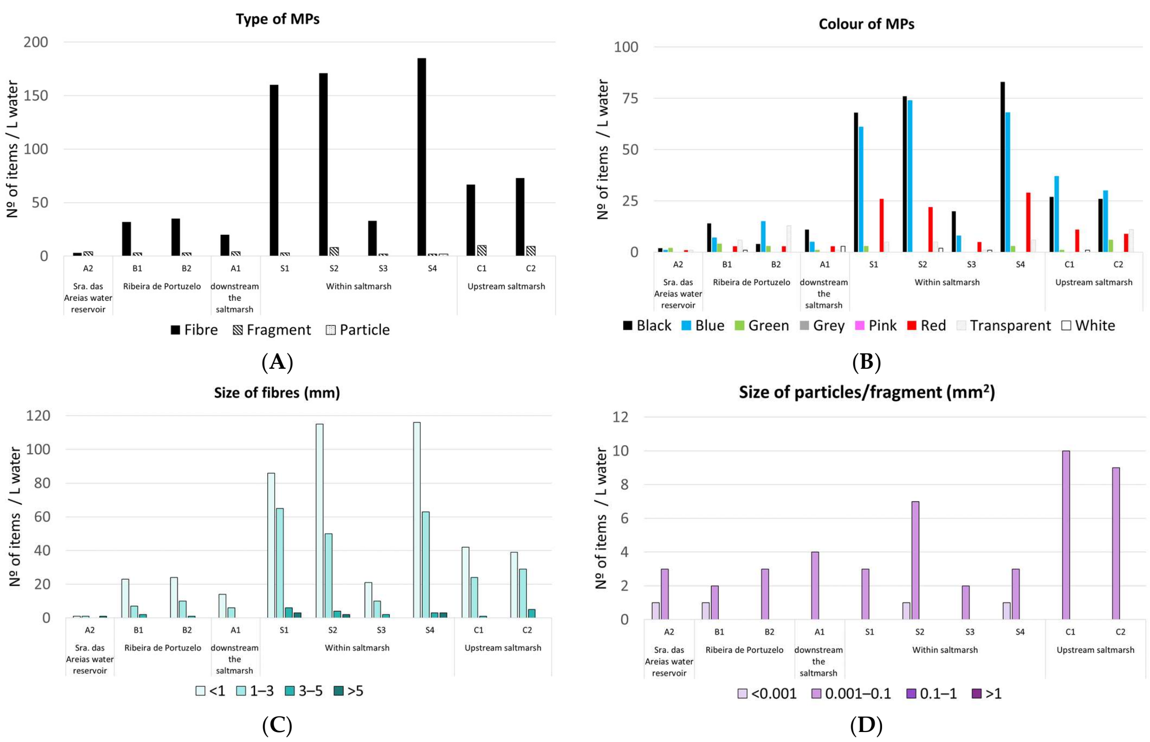

Figure 5. MPs content (number of items per L of water) and characterization from water samples collected in winter (February 2022), discriminated by: (**A**) Type of MPs; (**B**) Colour of MPs; (**C**) Size of fibres (mm); (**D**) Size of particles and fragments (mm^2).

In general, fibres were the dominant type of MPs found in water samples, mainly blue and black colours.

Examples of MPs observed in water samples are shown in Supplementary Material (Figure S2).

4. Discussion

The current results show that the estuarine area selected as the case study, the Lima river estuary, is contaminated with MPs. Several studies around the word clearly show that this contaminant is now ubiquitous in the environment, being found in diverse coastal habitats, including estuarine areas [9], such as that surveyed.

MP values observed in sediment samples varied between 250 and 2500 number of items/Kg dry sediment. Although direct comparison between MPs concentrations in different locations should be carefully carried out, because different sampling and analytical methodologies are used to quantify MPs [8,33] and the values currently observed are considerably high, higher than values reported in sediments of other estuaries around the world [9]. Nevertheless, the number of studies on estuarine areas is still low, and the current work contributes to data on MPs amounts in these areas.

Rivers can be major transportation routes for MPs from land to coastal areas and to the sea, which can be retained in these areas. So estuaries can be plastic reservoirs, retaining plastic debris [34]. In fact, several studies have indicated that the source of plastics and MPs is primarily derived from land-based sources, associated with human activities [9], which could be also observed in the estuarine area surveyed in this work. The great variety of particles found in the current study, which were of different shapes, sizes, and multiple colours, indicates that the MPs observed probably had multiple sources, including land-based ones. Furthermore, the polymers of some of the MPs found in the sediments, e.g., PE, PP, and PS, showed that the sources of the MPs were probably land-based sources, as these polymers are commonly found in packing material, bottles, and liquid containers.

The high diversity of MPs found in all samples analysed in the current study was also reported in a study carried out by Hope et al. [35], with most of the particles found being in sizes ranging between 0.201 and 5 mm, similar to the present work. Fibres and fragments were also the dominant types of MPs found. Another work conducted by Lourenço et al. [18] also stated that microfibres were recorded in almost all sediment samples (91%), being the most abundant type of MPs as also observed in the Lima river estuarine area currently surveyed. In the review presented by Xu et al. [36], they summarized that, from twelve estuarine areas, fibres were present in ten estuaries and fibres were the most abundant in 5 of them, with a very high percentage of abundance. Fibres are released every day, for example, when washing clothes in washing machines, as small fibres may escape and reach water bodies, accumulating in ecosystems. However, fibres can also originate from the degradation of other plastic items. As indicated, a significant amount of fibres were detected in samples collected in the Lima river estuarine area. However, for most of them, the identification of their polymer type was not possible, which prevented clearly attributing their source in the current study.

The current results clearly indicate that there are areas where MPs can accumulate in higher amounts. In fact, the two sites with higher MPs concentration in their sediments, Sra. das Areias and Salinas, are confined areas in the estuary, with lower hydrodynamics. The other site, Canoagem, is located in the margin of the river and is more exposed to tidal currents with higher hydrodynamics, which can decrease the deposition and retention of MPs. Comparing seasonal campaigns, sediment samples from the autumn season (November 2021) had a higher total number of MPs than the ones from the winter season (February 2022). This was probably due to the higher rainfall events observed in autumn that can increase river flow and the input of pollutants. It has been reported that a higher transport of plastics into estuarine and coastal marine environments can occur during heavy rainfall than during normal river flow conditions [37]. Furthermore, in the study carried out by Gupta et al. [38], a higher number of MPs was observed both in water and sediment samples collected in the rainy season compared to those collected in the dry season. Hence, the present study reinforces the fact that local and seasonal hydrodynamics influence the MPs retention capability of saltmarshes.

The levels of MPs in the Lima river estuarine water varied between 10 and 200 items/L water, again showing that the estuarine area is contaminated with MPs. The current results indicated that the saltmarsh can indeed be an area of MPs retention, as higher amounts of MPs were observed in the water collected within the saltmarsh than in other zones of the estuary. Despite MPs being found in water streams draining into the estuary, indicating that these streams can be possible MPs sources to the estuarine area, MPs levels were lower than those observed in the estuary, particularly in the water within the saltmarsh. These findings suggest that, in the Lima estuary, MPs in the water tend to be concentrated in the saltmarsh area. The saltmarsh area in the Lima estuary integrates several tidal islands that influence the tidal currents and lead to the existence of retention areas of plankton [39] and, as shown in the current study, also of MPs. Moreover, there can also be local MPs contamination sources within the saltmarsh, contributing to higher contamination in the water of this area.

Overall, a higher number of particles were commonly found in sediments, indicating that sediments can act like a trap for these particles. In fact, particles with low density will tend to remain more in the water column, whereas particles with higher density will tend to remain close to the bottom, ending up deposited in the sediments [40], which can be responsible for a high accumulation of plastics in estuaries, leading to the observed results.

In this study, although fibres were found in all water and sediment samples, particles were mostly found in sediment, a feature that could be related to both MPs density and shape. In addition to density, the shape and irregularity of the particle can also affect its distribution in the environment, as well as it vertical transport [41], being one of the main characteristics that determines the sinking velocity of a particle [42]. In the current study, smaller-sized fibres were observed in collected water samples, whereas in sediment, fibre sizes were slightly larger.

In the present study, in general, vegetated sediment had higher amounts of MPs, with the most frequent type of MPs in non-vegetated sediments being fibre, followed by fragments; whereas for vegetated samples, all types of MPs were present in almost the same proportions. Variable distributions of MPs, such as higher amounts of fibres in non-vegetated mudflats than in vegetated areas, have been observed in some studies [9]. Therefore, the presence of plants in the sediment can also affect the distribution and retention of MPs, which can also vary with MPs shape and density.

In the Lima estuary, a tendency toward a higher retention of MPs in sediments vegetated with *J. maritimus* was observed. This plant has a rhizome structure, different from that of *P. australis* or *S. maritima*, as described in the experimental section. The denser and more complex root system of *J. maritimus* may be able to retain MPs more efficiently within its rhizosediment. Plant structure, particularly their belowground structure, therefore seems to influence MPs distribution and retention. In fact, different plant coverage and stem density can induce different distribution patterns of MPs [12].

As observed in the current study, plastics, including MPs, can become trapped in vegetation [22]. For instance, Ivar do Sul et al. [43] observed that, in mangroves, plastic can be retained for several months to years, a distinct behaviour of that observed in beaches with no vegetation, with an average plastic residence time of less than one year [43]. Therefore, as observed, wetlands such as saltmarshes can be primary locations for the retention of MPs, even contributing to their degradation [44]. Han et al. [45] showed, through a runoff plot experiment, that vegetation cover can indeed prevent MPs in soils from being eroded, therefore increasing their retention. Furthermore, less dense MPs particles can increase their density when attached to biofilms, or adsorbing particulate matter, which can lead to their settling in sediments [46,47]. Hence, the revegetation of eroded areas and on shorelines with high MPs abundance can be an effective way of preventing plastics from entering aquatic habitats [45], and the current work re-enforces that the protection and regrowth of saltmarshes in estuarine areas should be promoted.

5. Conclusions

This work gives a first insight into MPs status in the Lima River estuary, where a large number of varied plastic items have been recorded, both in sediments and in water. The results clearly showed that vegetated sediments tend to have higher MPs concentrations, highlighting the role of saltmarsh sediments as MP sinks. Local and seasonal hydrodynamics also influence the retention capability of saltmarshes, with lower hydrodynamics areas more prone to accumulate MPs in their vegetated sediments. Despite using the Lima River estuary as a case study, the current results are very relevant, supporting the fact that saltmarshes can have a significant influence on the transport, distribution, and accumulation of MPs in estuarine areas, which can also occur in estuaries around the world with similar characteristics.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15071382/s1, Figure S1: Examples of MPs (blue fragments and red fibre) observed in sediment samples, Figure S2: Examples of MPs (fibres) observed in water samples.

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