water

Article

Identification, Abundance, and Distribution of Microplastics in Surface Water Collected from Luruaco Lake, Low Basin Magdalena River, Colombia

René A. Rojas-Luna [1], Luisa Oquendo-Ruiz [1], Carlos A. García-Alzate [2,3], Victoria A. Arana [4], Roberto García-Alzate [4] and Jorge Trilleras [5,*]

[1] Grupo de Estudios en Sistemática y Conservación-GESC, Programa de Maestría en Biología, Facultad de Ciencias Básicas, Universidad del Atlántico, Carrera 30 No. 8–49, Puerto Colombia 081007, Colombia
[2] Grupo de Estudios en Sistemática y Conservación-GESC, Programa de Ingeniería Ambiental y Sanitaria, Facultad de Ingeniería Ambiental y Sanitaria, Corporación Universitaria Autónoma del Cauca, Calle 5 No. 3-85, Popayán 190003, Colombia
[3] Grupo de Investigación Biodiversidad del Caribe Colombiano, Programa de Maestría en Biología, Facultad de Ciencias Básicas, Universidad del Atlántico, Carrera 30 No. 8–49, Puerto Colombia 081007, Colombia
[4] Grupo de Investigación Ciencias, Educación y Tecnología-CETIC, Programa de Maestría en Ciencias Químicas, Facultad de Ciencias Básicas, Universidad del Atlántico, Carrera 30 No. 8–49, Puerto Colombia 081007, Colombia
[5] Grupo de Investigación en Compuestos Heterocíclicos, Programa de Maestría en Ciencias Químicas, Facultad de Ciencias Básicas, Universidad del Atlántico, Carrera 30 No. 8–49, Puerto Colombia 081007, Colombia
* Correspondence: jorgetrilleras@mail.uniatlantico.edu.co

Citation: Rojas-Luna, R.A.; Oquendo-Ruiz, L.; García-Alzate, C.A.; Arana, V.A.; García-Alzate, R.; Trilleras, J. Identification, Abundance, and Distribution of Microplastics in Surface Water Collected from Luruaco Lake, Low Basin Magdalena River, Colombia. *Water* **2023**, *15*, 344. https://doi.org/10.3390/w15020344

Academic Editors: Gabriela Kalčíková and Ludmiła Polechońska

Received: 25 October 2022
Revised: 8 January 2023
Accepted: 11 January 2023
Published: 13 January 2023

Abstract: There are few studies on microplastic (MP) contamination in Colombia, and little is known about its impacts on continental aquatic ecosystems. This study evaluated, for the first time, the identification, abundance, and distribution of MP particles in the surface water of Luruaco Lake, in the low basin of the Magdalena River, Colombia, included in national programs in marine sciences and hydrobiological resources. Six stations and four samplings were established in the dry and rainy seasons. A total of 72 water samples were collected for microplastic extraction using hydrogen peroxide (H_2O_2) digestion, density separation with sodium chloride solution (NaCl), and filtration. The abundance of MPs ranged from 0 to 3.83 MPs·L^{-1}, with an average of 1.90 MPs·L^{-1} in the rainy season and 0.25 MPs·L^{-1} in the dry season. According to the calculated coefficient of microplastics impact, the contamination in the surface water of Luruaco Lake is "maximum" to "extreme" for fibers with an average length of 2.05 mm and "minimum" to "average" for fragments that are 0.35 mm in size on average. Polyester (PES, 57.9%), polystyrene (PS, 47.0%), and polyethylene terephthalate (PET, 35.3%) polymers were more abundant in surface water. The temporal variation of the MPs indicates contamination related to the discharges of the tributary streams to the lake in the rainy season.

Keywords: freshwater; lake; microplastics; plastics pollution; surface water

1. Introduction

In the development of societies, a substantial number of synthetic materials have been created. The introduction of these materials into nature causes aggressive impacts, and their residues have become, in recent years, most abundant, as well as most dangerous. In this context, as society develops, science tries to follow these advances to understand how anthropogenic activities impact environments. A clear example is the growing pollution by plastics. The versatility, durability, low-cost production, and resistance of plastics make them materials with infinite applications, increasing their use in agriculture, building, health, industry, sports, and products for personal and daily use [1,2]. A huge portion of the plastics produced annually around the world are disposed of incorrectly in inappropriate places, generating pollution problems, whose impact on the environment is not completely measured [3,4]. When plastic debris is exposed to physical, chemical, and biological processes in the environment, many plastic particles, known as microplastics (MPs), are generated. MPs are composed of several types of polymers and chemical additives, with sizes ranging from 1 μm to 5 mm of varied shapes and colors. They are classified as primary and secondary according to their origin. Primary MPs are produced industrially, while secondary MPs are formed by fragmentation of macroplastics [5]. According to scientific studies, water bodies are the main repository for microplastics, which is the main reason why increasing research is needed to identify, characterize, and quantify these contaminants and their associated risks. The majority of publications on this situation in Colombia have examined the presence of microplastics in coastal systems, with limited information on continental waters. With the aim of expanding studies on MP pollution in continental waters, for the first time, a scientific study is carried out on the presence, abundance, and distribution of microplastics in Luruaco Lake, Colombian Caribbean wetland system.

Luruaco Lake, which is a part of the Atlántico department complex of wetlands and floodplains, plays a crucial role in terms of subsistence for the riverside population of this municipality, by its provision of ecosystem services. The municipality of Luruaco (founded in 1533) has a population of approximately 27,000 people, with a tradition in craft trades that comes from the Mokaná–Caribbean, African, and Indigenous heritage in the area, and which is part of the national programs in marine sciences and hydrobiological resources [6].

The high concentration of MPs found is a warning sign of the potential impact on the biodiversity of this continental system, exposing the urgent need to expand studies and research that provide scientific information, as well as ecotoxicological data, to evaluate potential risks and strategic management of microplastic contaminants in lakes from the low basin of the Magdalena River, Colombia [5,7–9].

The risk of exposure to, and contact with, fauna is directly proportional to the quantity and permanence of microplastics in freshwater ecosystems [10]. MPs have direct effects on aquatic organisms; for example, they make it difficult to ingest natural prey due to the obstruction of the digestive tract and the reduction in swimming speed [11–14]. Studies related to plastic debris indicate that its abundance in aquatic systems comes from the surrounding terrestrial environment, demonstrating the close connection of aquatic and terrestrial systems [15,16]. In Luruaco Lake (Colombia), anthropogenic interferences on water body shores, as a result of activities such as livestock farming, overfishing, agriculture, and use of water resources for residential tasks, as well as the mouth of streams with a high load of organic and inorganic matter, affect the environmental quality of this ecosystem, impacting ecological, economic, and social aspects. Luruaco Lake, according to its geological and hydrographic history, was one of the mouths of the Magdalena River, the most important river in Colombia and one of the world's largest (1612 km long with a discharge volume of 7100 $m^3 \cdot s^{-1}$) tropical rivers [17,18].

Within the system of wetlands and floodplains of the Atlántico department, Colombia, Luruaco Lake is a key zone for water and food supply, and there is currently no environmental information that allows for the evaluation of microplastic contamination in this ecosystem. To contribute with research that shows the presence of this contaminant in Luruaco Lake, we quantified MPs in the surface water in different temporal variations associated with rainy and dry periods for 2 years (2021–2022), as a result of the initial investigation of flood-prone areas in the lower basin of the Magdalena River, Colombia.

2. Material and Methods

2.1. Field Sampling and Data Collection

Luruaco Lake is located to the southwest of the Atlántico department (Figure 1), at 25 m above sea level, with an area of 420 ha, enclosed by the Luruaco mountain range, which is part of a mountain system with heights less than 500 m above sea level. Luruaco Lake is an isolated body of water, without direct contact with the Magdalena River, although it is part of its lower basin [17,18]. Its main tributaries are the Mateo, Negro, and Limón streams and a channel that connects it with Tocagua Lake; however, the latter was interrupted by the construction of the Troncal del Caribe highway that connects the cities of Barranquilla-Atlántico with Cartagena de Indias-Bolívar [19,20].

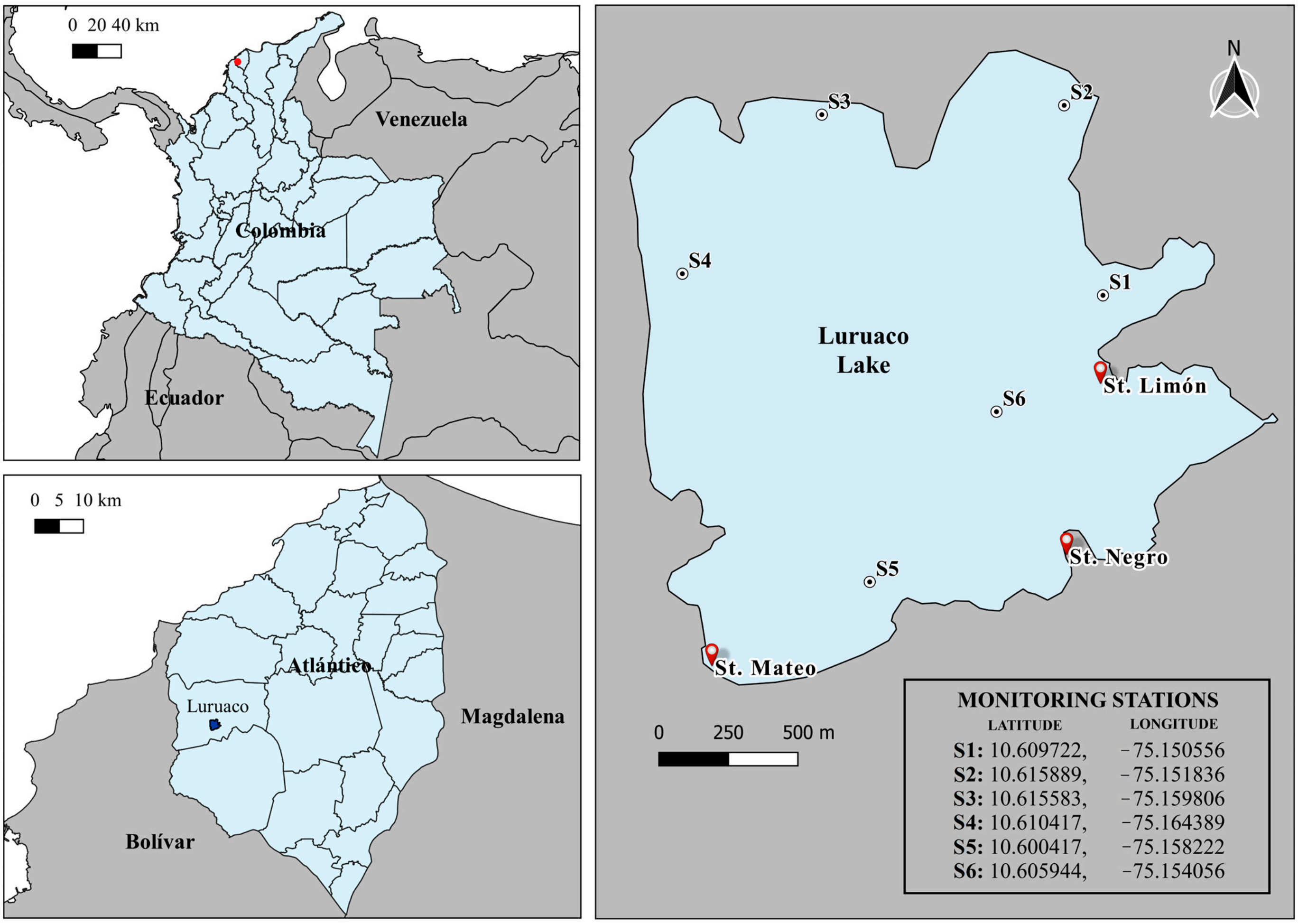

Figure 1. Geographical location of Luruaco Lake, Colombia. Monitoring stations and the mouths of the Limón, Mateo, and Negro streams.

Six stations and four monitoring events were established to cover the lake area and different temporal variations associated with rainy (September–November 2021) and dry (March–May 2022) periods. Surface water samples were collected at a depth of 30 cm, before filtering with a 23 µm net and a 250 mL capacity collection container, and then transferring into glass jars within 15 mL of a formaldehyde solution 10% in H_2O. This procedure was carried out until completion of a volume of 20 L of surface water/station, taking three repetitions of 20 L of sample and storing them. The glass jars were previously washed three times with 90% ethanol.

Lake water was monitored in situ, and measurements of temperature, pH, dissolved oxygen, and conductivity were taken using a multiparameter (YSI ProPlus, YSI Inc., Yellow Springs, OH, USA). Water samples were collected, preserved, and stored for ex situ measurements of hardness and alkalinity, using commercially purchased physicochemical kits (Hanna Instruments, Vöhringen, Germany).

2.2. Laboratory Processing

Methods reported in the literature were used for the treatment of water samples and MP extraction [21–23]. The water samples were treated with 40 mL of H_2O_2 (30% w/v) and stirred (Heidolph Incubator 1000 and Heidolph Unimax 1010, Heidolph Instruments GmbH & Co. KG, Schwabach, Germany) for 6 h at 60 °C to remove organic matter. Then, 100 mL of saturated NaCl solution was added to the samples and stirred for 5 min. The samples were left undisturbed for 24 h. The supernatant was filtered with glass microfiber filters (grade GF/C, 1.2 µm, Whatman) and stored in petri dishes. Under a stereomicroscope (Leika S8 Apo), a visual analysis was performed on the MPs isolated and collected on the filters to quantify the particles and record their physical characteristics. The tpsDig and tpsUtil programs for digitizing landmarks and outlines for geometric morphometric analyses were used. The small plastic particles were categorized as fibers, films, pellets, fragments, and foam. Pellets (or spheres) are manufactured for a specific purpose, primarily in the personal care industry. The fragmentation of plastics results in small plastic particles with irregular shapes. Compared to fragments, films are flat, flexible particles with typically smooth edges. Foams are associated with expanded polystyrene, although there are other types, and they are particles with a granular appearance that can deform under pressure and have some elasticity. Fibers are defined as particles that have the same thickness along their entire length, which must be greater than their width, and they are usually associated with detachment from textiles and fishing nets [24,25].

2.3. µ FTIR Analysis

To identify the type of polymer, representative samples of microplastics were selected. The suspected MPs on filters were identified using a micro-attenuated total reflectance Fourier–transform infrared spectroscope (ATR–FTIR microscope, LUMOS II, Bruker Optics GmbH & Co. KG, Ettlingen, Germany) equipped with a thermoelectrically cooled mercury cadmium telluride (TE–MCT) detector and automated ATR probe (Ge crystal). Analysis was performed with a spectral wavenumber range of 4000 and 670 cm^{-1}, with a resolution of 4 cm^{-1} and 64 scans. The obtained spectra were compared with the database for verification (ATR-Polymer library complete (Vol. 1–4), KIMW ATR–IR Polymer libraries) and a matching degree >75% between the sample and standard spectra was considered acceptable [26,27].

2.4. Prevention and Control of Contamination

To minimize contamination with airborne MPs during sample collection and laboratory processes, inert materials and instruments such as stainless steel, glass, and aluminum were used. All solutions were prepared with ultrapure water and later filtered. During the sampling and laboratory stage, control experiments were carried out by placing wet filters with distilled water (n = 3 for each set of samples) [28]. Filters from control experiments were examined by the visual method under a stereomicroscope, and no MP particles were found.

2.5. Data Analysis

The number of microplastics is expressed as a function of density by dividing the total number of particles found in the volume of water analyzed from each station and sampling event ($MPs \cdot L^{-1}$). The physicochemical variables of the water, as well as the shape and color of the MPs, were analyzed using descriptive statistics. The data distribution of physicochemical parameters and MP densities at each station and sampling event were evaluated using the Shapiro–Wilk normality test. The Kruskal–Wallis and Friedman tests allowed the evaluation of spatial and/or temporal changes of the physicochemical data because the data did not follow a normal distribution. Similarly, for data with a normal distribution, a one-way ANOVA was applied to identify the variations in MP density between stations and sampling events. Additionally, a post hoc test (Tukey's pairwise) was used to estimate the statistical differences in MP density during the dry and rainy seasons.

A generalized additive model (GAM) was used for the evaluation of the effects of water temperature (°C), depth (m), distance of the stations in relation to the tributary streams of the lake (Mateo, Negro, and Limón streams in km), and precipitation (mm), with respect to MP density (MPs·L^{-1}). The distance between monitoring stations and streams was determined using Google Earth Pro; precipitation was obtained from measurements made by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) in the municipality of Luruaco during the months of monitoring. The CMPI proposed by Rangel-Buitrago and collaborators was used to evaluate the impacts of microplastic shapes on ecosystems (Table 1). This coefficient is the relationship between the total amount of a specific form of MP (i.e., fibers and fragments) and the total number of MPs found in a sampling unit [29].

Table 1. This coefficient evaluates the impact of different categories of microplastics in surface water of Luruaco Lake [29].

Coefficient of Microplastics Impact (CMPI)	
$CMPI = \frac{Specific\ MPs'\ Shape}{Total\ MPs'}$	0.0001 to 0.1: Minimum
	0.11 to 0.5: Average
	0.51 to 0.8: Maximum
	0.81 to 1: Extreme

3. Results

3.1. Physicochemical Characterization of the Habitat

The surface temperature of the water presented an average value of 30.1 °C (27.1–31.9 °C) during the samplings associated with the rainy period and 31.3 °C (29.9–35.1 °C) during those associated with the dry period. The conductivity registered high values of 1224 µs/cm (1056–1390 µs/cm) in the rainy period and 1258 µs/cm (1154–1302 µs/cm) in the dry period; alkalinity in general was high, with an average of 313 mg/L $CaCO_3$ (240–360 mg/L) and 297 mg/L (240–390 mg/L) in the rainy and dry periods, respectively.

Regarding the average value of dissolved oxygen, it was low at 5.64 ± 1.46 mg/L; the lake presented moderately hard water with hardness values that ranged between 45 and 150 mg/L, with an average of 116.33 ± 9.47 mg/L. The pH of the water tended toward acidity in the four samplings carried out and obtained higher values in S4 and S5, with an average of 6.15 (4.0–9.5) and 5.50 (2.6–9.6), revealing maximum values in the rainy period and minimum values in the dry period, with respect to the average of the other monitoring stations (S1: 3.73, S2: 4.23, S3: 3.35, and S6: 4.03). There were no statistically significant differences in the variables between samplings (F: 7.1143, p-value: 0.0683) and stations (H: 0.1785, p-value: 0.9993).

3.2. Abundance and Distribution of Microplastics

Microplastic particles were found in surface water from the monitoring stations in Luruaco Lake (Figure 2A), with an average range of 0.73 to 1.47 MPs·L^{-1}. MPs density varied spatially, with maximum average values of 1.47 and 1.39 MPs·L^{-1} in S5 and S4, respectively. On the other hand, the minimum average value was 0.73 MPs·L^{-1} in the first station (Figure 2A), without statistically significant differences (F: 0.2274, p-value: 0.9402), demonstrating the importance of the dynamics of the lake water flow, where the main movements occurred in an east–west direction, directing the residual waters of the Limón, Negro, and Mateo streams towards the location of the S4 and S5 (Figure 2B).

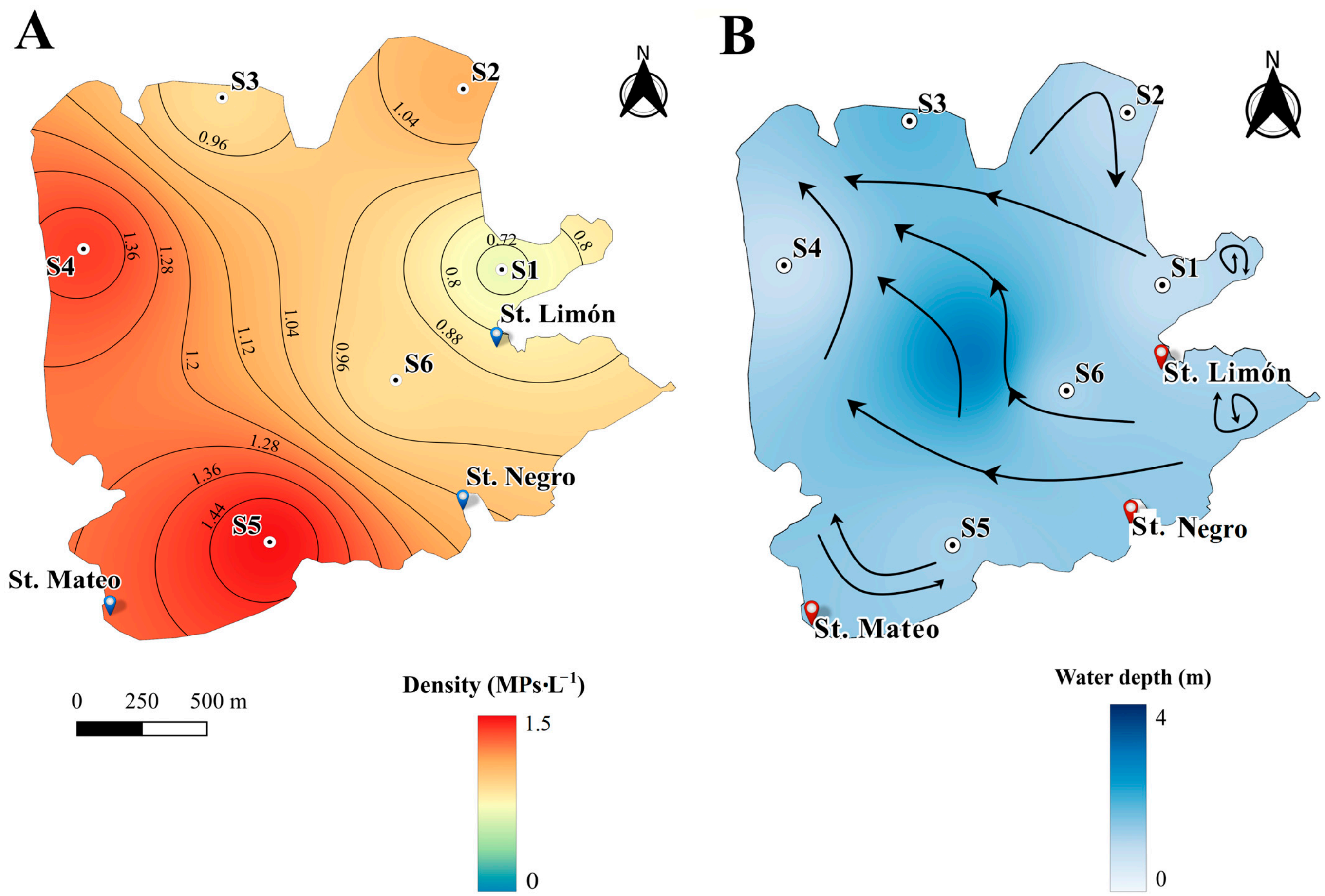

Figure 2. (**A**) Average density and distribution of MPs in surface water of Luruaco Lake, Atlántico (Colombia). (**B**) Measured depth and constant flow of water from Luruaco Lake. Taken and modified from Saita et al., [19].

During the season associated with rain, the density of microplastics ranged from 0.62 to 3.83 MPs·L^{-1}, with an average of 1.41 and 2.38 MPs·L^{-1} in the first and second sampling, respectively (Figure 3A,B). In contrast, the MP density in the dry season ranged from 0 to 0.63 MPs·L^{-1} (S3: no MP particles were found in the third sampling), with an average value of 0.17 MPs·L^{-1} in the third sampling and 0.32 MPs·L^{-1} in the fourth sampling (Figure 3C,D); there were statistically significant differences between the samplings in the rainy season compared to the dry season (F: 35.59, p-value: 0.0001), supported by Tukey's pairwise analysis (sampling 1 and 2, p–value: <0.05; sampling 3 and 4, p-value: >0.05).

The variables analyzed in the GAM model reflected that the greatest effect on MP density was related to the rainy season, with statistically significant differences (p-value < 0.05), together with the water temperature, which depended on this same factor (p-value < 0.1) (Figure 4); similarly, contamination by MPs in the monitoring stations was affected by proximity to the mouth of the Mateo stream, but without significant differences (Table 2), which shows a great abundance of these particles when the rains formed streams that washed soils and dragged waste material into the lake, mainly in the riparian areas associated with agriculture and livestock farming.

Table 2. Effects estimated by the Generalized Additive Model of the density of microplastics in surface water in the Luruaco Lake, *p*-value: *** (<0.01), ** (<0.05), * (<0.1).

Parametric Coefficients	Estimate	Standard Error	*p*-Value
Intercept	118.52	23.81	0.0075 ***
Effects	df	*F*	*p*-value
Precipitation	1	7.91	0.01 **
Water surface temperature	1	4.29	0.05 *
Distance from Mateo Stream	1	0.52	0.48
Distance from Limon Stream	1	0.44	0.52
Distance from Negro Stream	1	0.02	0.89
Water depth	1	1.81	0.19
Total deviance explained	35.4%		

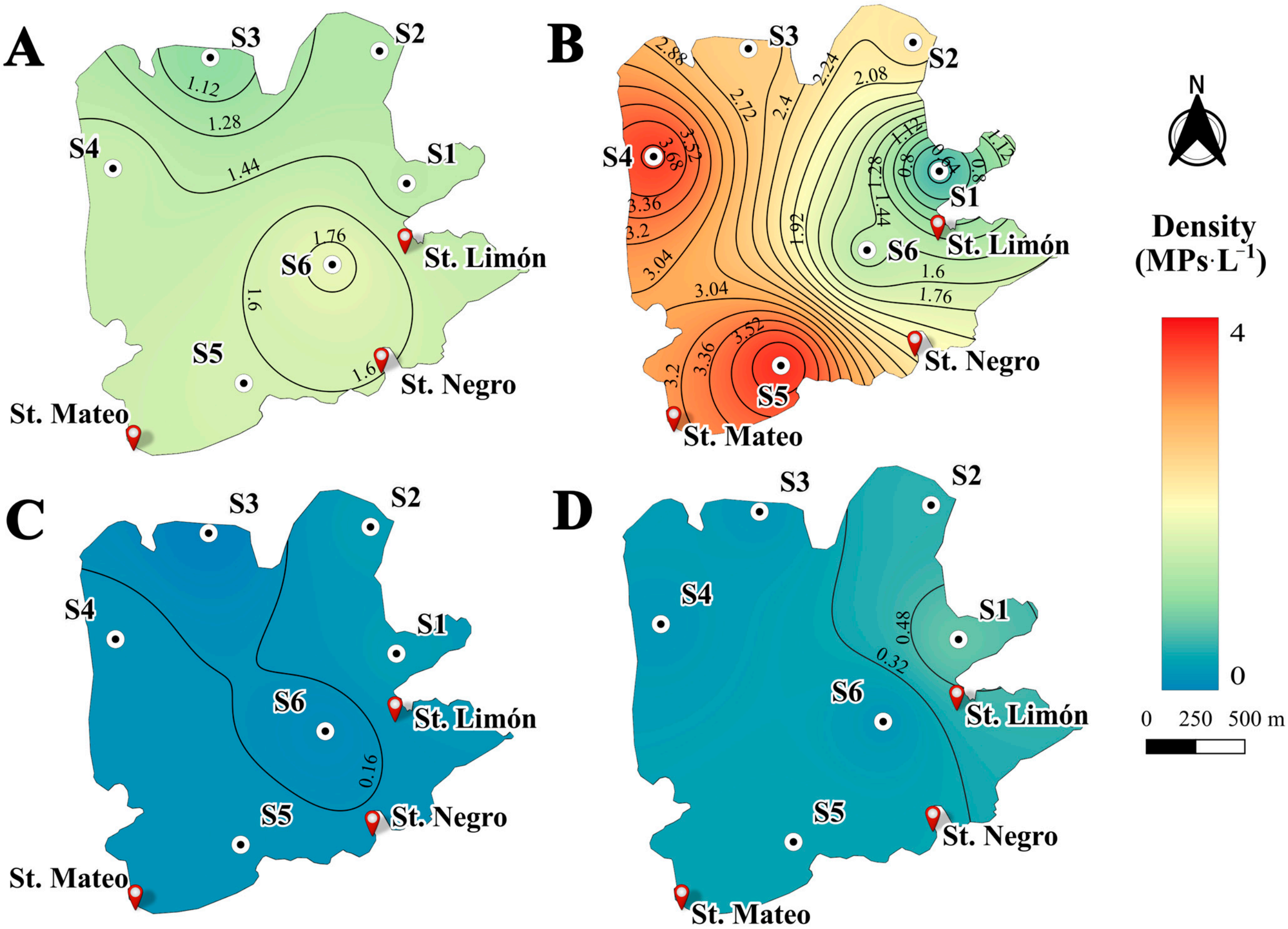

Figure 3. Density and distribution of microplastics in the surface water of Luruaco Lake in the rainy season: (**A**) September 2021, (**B**) November 2021 and dry season: (**C**) March 2022, (**D**) May 2022.

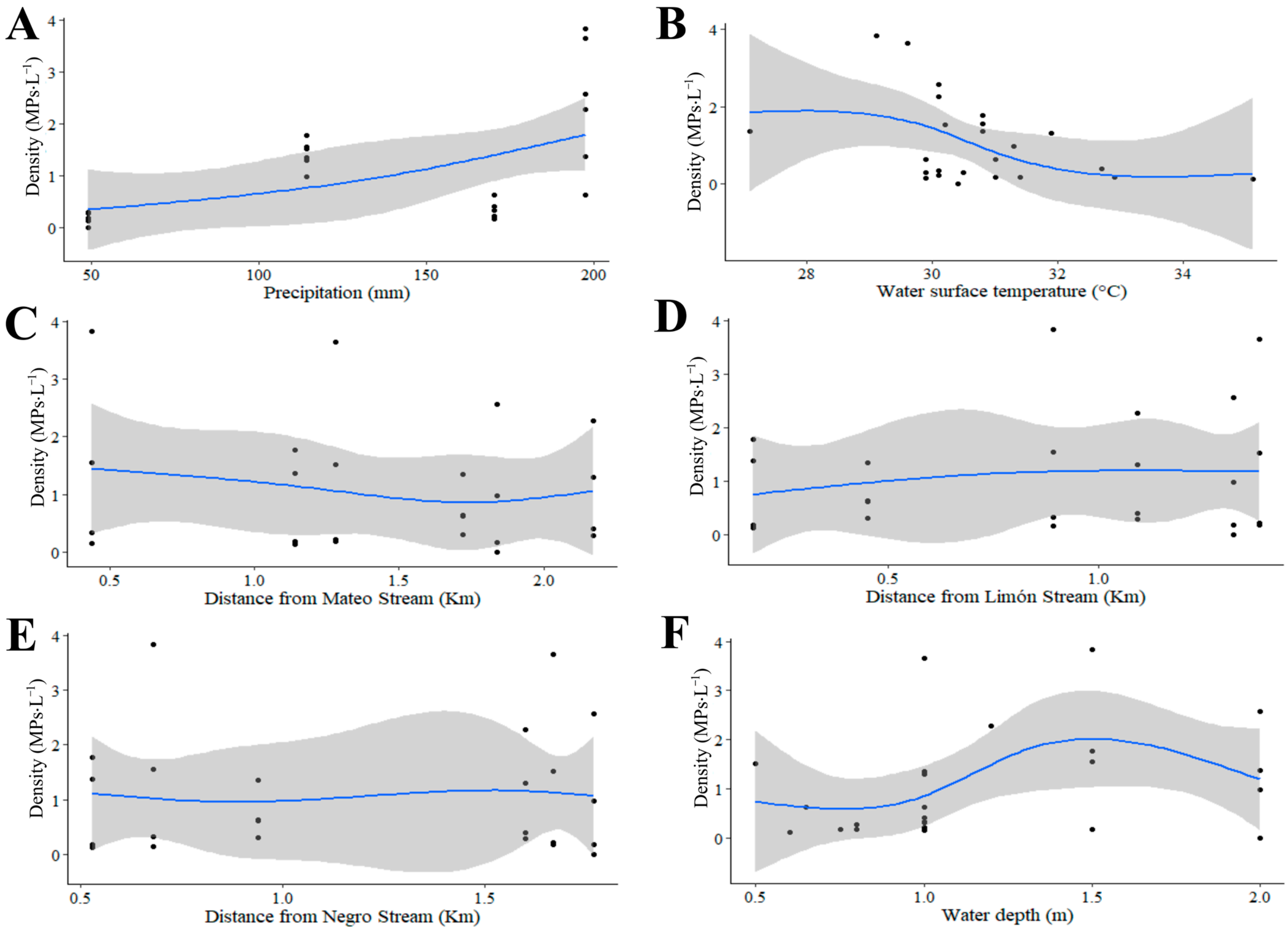

Figure 4. Relationship between the density of microplastics (MPs·L^{-1}): (**A**) precipitation (mm), (**B**) surface temperature of the water, (**C**) distance from the Mateo stream (km), (**D**) from the Limón stream (km), (**E**) from the Negro stream (km), and (**F**) depth of the water (m), through a generalized additive analysis (p-value see Table 2). Shaded areas indicate 95% confidence intervals, and black dots represent observed data.

3.3. Typology and Color of Microplastics

Four different forms were recorded within the typology of microplastics; fibers predominated with 78.9%, followed by fragments (20.8%), foams (0.2%), and pellets (0.1%). Furthermore, 12 colors were determined in the macroscopic analysis of the four shapes (Figure 5). Colors such as gold (67.9%), black (17.1%), and white (11.2%) predominated in the fragments; the colors that were most abundant in fibers were black (49.5%) and blue (34.6%). Lastly, regarding the pellets and the foam, the predominant color was white (Figure 5).

The fibers had an average length of 2.05 mm (0.74–4.55 mm), fragments had an average length of 0.35 mm (0.08–1.01 mm), and pellets had an average diameter of 0.22 mm (0.19–0.24 mm) (Figure 6).

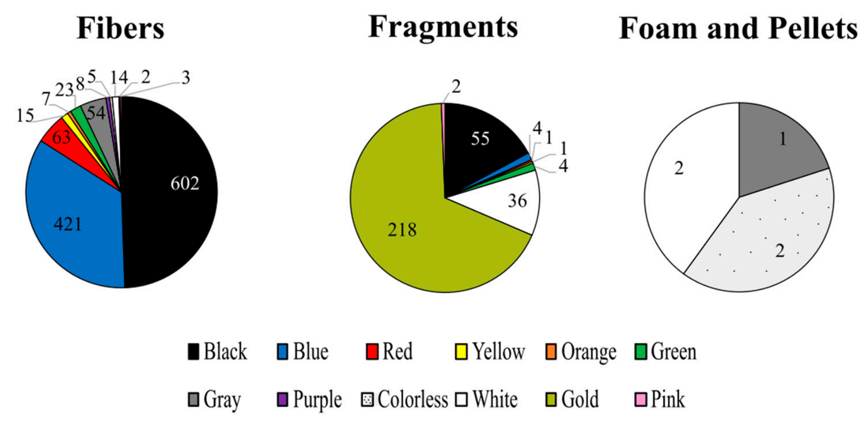

Figure 5. Number of MP particles in terms of shape and color, present in the surface water from Luruaco Lake, Atlántico, Colombia.

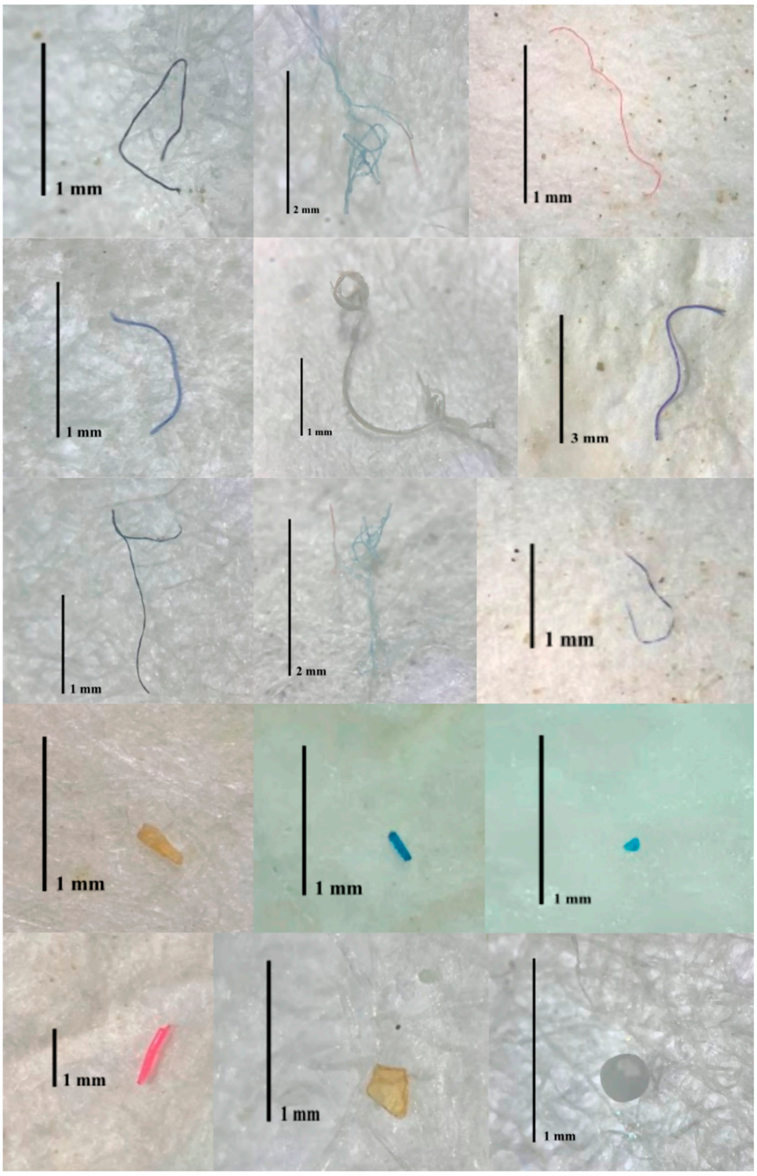

Figure 6. Examples of Microplastics found on the surface water of Luruaco Lake, Low Basin Magdalena River, Colombia.

3.4. Polymer Type

A representative group of fibers and fragments was selected for μFTIR analysis of particles collected at six stations and four monitoring events. The analysis confirmed that 85.2% of the particles were plastics; the remaining 14.8% corresponded to non-synthetic materials (cotton and flax), which were removed from the dataset and excluded from calculations. For the fibers, polyester (PES) was the most common polymer type (57.9%), followed by polyamide (PA, nylon) with 21.0%, polypropylene (PP) with 15.8%, and polyvinyl chloride (PVC) with 5.3%. For fragments, polystyrene (PS) and polyethylene terephthalate (PET) were the polymers with the highest proportion, with 47.0% and 35.3%, respectively, followed by polypropylene (11.8%) and PVC (5.9%). There was no great variability in the compositions of MP polymers in the surface waters at the different monitoring events.

3.5. Microplastic Contamination Status

In order to include an assessment of the impact of microplastic shapes and compare the information with the few existing studies of microplastic concentrations in natural matrices, the Coefficient of Microplastic Impact (CMPI) was used as an indicator (Table 3). The CMPI recorded a "maximum" (0.79) fiber pollution impact and an "average" (0.21) fragment impact for Luruaco Lake. Moreover, 67% of the stations obtained an "extreme" impact due to contamination with fibers, while the same percentage was recorded for an "average" impact due to contamination with fragments. S1 and S6 exhibited "minimal" impact considering the fragments, but "extreme" impact using the fibers as part of the CMPI.

Table 3. Pollution status by MPs of the monitoring stations using the Microplastic Impact Coefficient (CMPI) in fibers (F) and fragments (Fr).

Stations	CMPI-F	CMPI-F Mean	CMPI-Fr	CMPI-Fr Mean
1	0.93	Extreme	0.07	Minimum
2	0.82	Extreme	0.17	Average
3	0.66	Maximum	0.33	Average
4	0.64	Maximum	0.35	Average
5	0.84	Extreme	0.16	Average
6	0.93	Extreme	0.07	Minimum

4. Discussion

The baseline was established with respect to the study of the characterization and evaluation of the impacts of MPs in freshwater ecosystems in the Atlántico department and the Caribbean region, complementing the research reported in marine and coastal environments [29–31]. In addition, there is limited information about the distribution and abundance of MPs in freshwater ecosystems both in Colombia and in the rest of South America [22]. Pollution by MPs in Luruaco Lake presented temporal variation associated with the rainfall regime: 1.90 MPs·L^{-1} in the rainy season and 0.25 MPs·L^{-1} in the dry season, values higher than those recorded in Ciénaga Grande de Santa Marta, Colombia [32].

The stations with the highest MP density were those close to the rural area, to the southwest of the municipality (S4 and S5), as well as those with the highest agricultural and livestock development, according to the spatial pattern of accumulation of MPs in the surface water from Luruaco Lake. In addition, they were close to the mouths of the Negro and Mateo streams. On the other hand, the stations near the mouth of the Limón stream and the municipal heat of Luruaco (S1 and S6) registered lower density. There is no solid waste management in the crop and livestock areas; accordingly, the soils are washed by the rains and flow into the Mateo and Negro streams, before finally entering into the lake. A similar trend was reported in investigations with other contamination indicators [19]. Similarly, the impact increases with the flow of water from the east (mouth of the Limón stream and municipal heat) to the west.

As the concentration of microplastics was higher in stations near the rural area compared to those near the municipality, more than it being associated with the activities carried out in each zone, it may have been influenced by the flow of the water mass. Watkins et al. (2019) demonstrated that this MP–water flow relationship is direct [33]. This scientific study indicated that, in areas with low water movement, the density of microplastics was higher than in areas with higher flow, indicating that areas of low water flow are appropriate to increase the dispersion and mobility of microparticles in surface water. This relationship is also evident in our results, in which we found a lower density of microplastics in surface waters of Luruaco Lake in areas close to the municipality and stream mouth, but a higher density in areas where artisan agricultural activities are concentrated.

Regarding the typology or morphology of the MPs, the fibers recorded a value above 60% and the percentage of fragments was close to 20%, which is consistent with most studies in freshwater systems [22]. The high number of fibers and their wide range of colors may be related to the discharge of wastewater associated with washing clothes in the municipal heat or on the shores of the lake [34], or to the fragmentation of the synthetic material from the fishing nets used by the fishermen in the area. Fragment contamination results from improper solid waste disposal, with some waste thrown from the main highway "Troncal del Caribe" by people, or by riverside settlements directly into the lake, which also includes runoff in the rainy season of macroplastics located in the sediment around the ecosystem (Figure 7) [35].

Figure 7. Inappropriate disposal of plastic waste in Luruaco Lake. (**A**,**B**): Limón stream bank. (**C**,**D**): Macroplastics found on the shores of the lake in front of the main highway "Troncal del Caribe".

The contamination status of Luruaco Lake exhibited a tendency from high to very high MP density, with an extreme impact of fibers and the use of different fishing nets increasing their occurrence and abundance. These results agree with the environmental overview of the Atlántico department, whereby what is observed in the coastal zone is reflected in continental ecosystems; in rainy periods, the problem is magnified by the dragging of plastic of different sizes from urban areas to the environment [29].

Scientific studies on microplastic pollution in Colombia are few and comparing our results with other published studies can be difficult due to differences in sampling methodologies, monitoring and identification techniques, and microplastic concentration units.

Additionally, factors such as human activity, population density, meteorological conditions, and hydrological processes that affect the distribution, quantity, and movement of microplastics must be considered. However, there are recent reports in the literature using similar methodologies to determine the abundance and distribution of microplastics in surface water of small rural lakes [36]. One study was carried out on 14 small rural lakes in the Muskoka–Haliburton region in southcentral Ontario, Canada. The concentration of microplastics in the study lakes ranged from 1.02 to 2.39 MPs·L^{-1}, with an average concentration of 1.78 MPs·L^{-1}. According to our results, the determined microplastic densities were similar, values were in the range 0–3.83 MPs·L^{-1}, with an average of 1.07 MPs·L^{-1}. Both studies also agreed that fibers and fragments were the dominant microparticle shapes identified.

Regarding the MP composition found in Luruaco Lake, μFTIR analysis indicated four types of polymers detected for fibers (polyester, polyamide, polypropylene, and polyvinyl chloride) and two for fragments (polystyrene and polyethylene terephthalate). Polyester (PES, 57.9%), polystyrene (PS, 47.0%), and polyethylene terephthalate (PET, 35.3%) polymers were more abundant in surface water.

5. Conclusions

These results are part of a scientific investigation that evaluates, for the first time, the abundance and distribution of microplastics in the Colombian Caribbean wetland complex. Four different forms of microplastics (fibers, fragments, foams, and pellets) were found in all surface water samples collected, with fiber and fragment forms predominating, with average sizes of 2.05 mm and 0.35 mm, respectively. Six types of polymers (PES, PA, PP, PVC, PS, and PET) were detected in the composition of plastic microparticles. Most MPs detected in surface water were of fiber or fragment form, of gold and black color, and composed of polyester, polystyrene, and polyethylene terephthalate. The density of secondary microplastics in surface water of Luruaco Lake is higher in the rainy season and in areas with low water flow. Given that artisanal fishing is the main activity, and that the fibers are widely distributed, it is likely that this activity contributes to microplastics pollution. Basic information is needed to estimate the impact and risk of exposure to these particles, along with the development of education and environmental policies to reduce, regulate, and mitigate the effects of MP contaminants in aquatic ecosystems, mainly in flood seasons, in order to preserve the water quality, biodiversity, and attractiveness of the ecosystem.

Author Contributions: Conceptualization, C.A.G.-A. and V.A.A.; methodology, V.A.A.; software, C.A.G.-A.; formal analysis, R.A.R.-L. and L.O.-R.; investigation, C.A.G.-A., V.A.A., J.T. and R.G.-A.; resources, J.T.; writing—original draft preparation, R.A.R.-L.; writing—review and editing, J.T.; project administration, J.T.; funding acquisition, J.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research and APC were funded by MINISTERIO DE CIENCIA TECNOLOGÍA E INNOVACIÓN (MINCIENCIAS)–Colombia, grant number 1116–852–72530 (agreement 80740–485–2020) and the Universidad del Atlántico.

Data Availability Statement: Not applicable.

Acknowledgments: This work is a contribution from research groups "Investigación en Compuestos Heterocíclicos", "Investigación Ciencias, Educación y Tecnología–CETIC", "Investigación Biodiversidad del Caribe Colombiano", "Estudios en Sistemática y Conservación", Corporación Universitaria Autónoma del Cauca and Universidad del Atlántico.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xia, W.; Rao, Q.; Deng, X.; Chen, J.; Xie, P. Rainfall is a significant environmental factor of microplastic pollution in inland waters. *Sci. Total Environ.* **2020**, *732*, 139065. [CrossRef] [PubMed]
2. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, 25–29. [CrossRef] [PubMed]
3. Horton, A.A. Plastic pollution: When do we know enough? *J. Hazard. Mater.* **2022**, *422*, 126885. [CrossRef] [PubMed]
4. Millican, J.M.; Agarwal, S. Plastic Pollution: A Material Problem? *Macromolecules* **2021**, *54*, 4455–4469. [CrossRef]
5. Zhang, K.; Hamidian, A.H.; Tubić, A.; Zhang, Y.; Fang, J.K.; Wu, C.; Lam, P.K. Understanding plastic degradation and microplastic formation in the environment: A review. *Environ. Pollut.* **2021**, *274*, 116554. [CrossRef]
6. Martínez, L.; Dámato, G. Identity and environmental law protection of the Mokaná indigenous people in Malambo, Atlántico. *Jurídicas CUC* **2022**, *18*, 303–334. [CrossRef]
7. Cera, A.; Cesarini, G.; Scalici, M. Microplastics in Freshwater: What Is the News from the World? *Diversity* **2020**, *12*, 276. [CrossRef]
8. Hale, R.C.; Seeley, M.E.; La Guardia, M.J.; Mai, L.; Zeng, E.Y. A Global Perspective on Microplastics. *J. Geophys. Res. Ocean.* **2020**, *125*, e2018JC014719. [CrossRef]
9. Caruso, G. Microplastics as vectors of contaminants. *Mar. Pollut. Bull.* **2019**, *146*, 921–924. [CrossRef]
10. Dos Santos, T.; Bastian, R.; Felden, J.; Rauber, A.M.; Reynalte–Tataje, D.A.; de Mello, F.T. First record of microplastics in two freshwater fish species (*Iheringhthys labrosus* and *Astyanax lacustris*) from the middle section of the Uruguay River, Brazil. *Acta Limnol. Bras.* **2020**, *32*, 1–6. [CrossRef]
11. Bajt, O. From plastics to microplastics and organisms. *FEBS Open Bio.* **2021**, *11*, 954–966. [CrossRef] [PubMed]
12. Issac, M.N.; Kandasubramanian, B. Effect of microplastics in water and aquatic systems. *Environ. Sci. Pollut. Res.* **2021**, *28*, 19544–19562. [CrossRef] [PubMed]
13. Barboza, L.G.A.; Vieira, L.R.; Guilhermino, L. Single and combined effects of microplastics and mercury on juveniles of the European seabass (*Dicentrarchus labrax*): Changes in behavioural responses and reduction of swimming velocity and resistance time. *Environ. Pollut.* **2018**, *236*, 1014–1019. [CrossRef] [PubMed]
14. Cole, M.; Lindeque, P.; Fileman, E.; Halsband, C.; Goodhead, R.; Moger, J.; Galloway, T.S. Microplastic ingestion by zooplankton. *Environ. Sci. Technol.* **2013**, *47*, 6646–6655. [CrossRef]
15. Malizia, A.; Monmany-Garzia, A.C. Terrestrial ecologists should stop ignoring plastic pollution in the Anthropocene time. *Sci. Total Environ.* **2019**, *668*, 1025–1029. [CrossRef]
16. de Souza Machado, A.A.; Kloas, W.; Zarfl, C.; Hempel, S.; Rillig, M.C. Microplastics as an emerging threat to terrestrial ecosystems. *Glob. Change Biol.* **2018**, *24*, 1405–1416. [CrossRef]
17. Salgado, J.; Shurin, J.B.; Vélez, M.I.; Link, A.; Lopera–Congote, L.; Gonzalez–Arango, C.; Jaramillo, F.; Åhlén, I.; de Luna, G. Causes and consequences of recent degradation of the Magdalena River basin, Colombia. *Limnol. Oceanogr. Lett.* **2022**, *7*, 451–465. [CrossRef]
18. Villalón, J.; Vega, A. Aspectos históricos: El sur del Atlántico: Cuatro mil Años de Historia. In *Sur del Atlántico: Una Nueva Oportunidad*; Alvarado, M., Ed.; Fundación Promigas: Barranquilla, Colombia, 2016; pp. 28–49.
19. Saita, T.M.; Natti, P.L.; Cirilo, E.R.; Romeiro, N.M.L.; Candezano, M.A.C.; Borja Acuña, R.A.; Gutiérrez Moreno, L.C. Proposals for Sewage Management at Luruaco Lake, Colombia. *Environ. Eng. Sci.* **2022**, *38*, 1140–1148. [CrossRef]
20. García–Alzate, C.A.; Gutiérrez–Moreno, L.C.; De la Parra Guerra, A.C. El Embalse de El Guájaro: Diagnóstico Ambiental y Estrategias de Rehabilitación. In *Sur del Atlántico: Una Nueva Oportunidad*; Alvarado, M., Ed.; Fundación Promigas: Barranquilla, Colombia, 2016; pp. 150–181.
21. Gupta, D.K.; Choudhary, D.; Vishwakarma, A.; Mudgal, M.; Srivastava, A.K.; Singh, A. Microplastics in freshwater environment: Occurrence, analysis, impact, control measures and challenges. *Int. J. Environ. Sci. Technol.* **2022**, *408*, 127317. [CrossRef]
22. Li, C.; Busquets, R.; Campos, L.C. Assessment of microplastics in freshwater systems: A review. *Sci. Total Environ.* **2020**, *707*, 135578. [CrossRef]
23. Al-Azzawi, M.S.M.; Kefer, S.; Weißer, J.; Reichel, J.; Schwaller, C.; Glas, K.; Knoop, O.; Drewes, J.E. Validation of Sample Preparation Methods for Microplastic Analysis in Wastewater Matrices—Reproducibility and Standardization. *Water* **2020**, *12*, 2445. [CrossRef]
24. GESAMP. *Guidelines or the Monitoring and Assessment of Plastic Litter and Microplastics in the Ocean*; Kershaw, P.J., Turra, A., Galgani, F., Eds.; IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection: London, UK, 2019; 130p.
25. Smith, W.S.; Freitas-Lima, T.R.; Bertolino-Castelo, N.S.; Cavallari, D.E.; Pinheiro, L.A.S.; Soinski, T.A.; Stefani, M.S.; Silva-Oliveira, J.; Silva, F.L. Peixe e Plástico em Ecossistemas de Água Doce: Contribuição da Ciência Brasileira e Pesquisas Futuras. In *Microplásticos nos Ecossistemas: Impactos e Soluções*; Pompêo, M., Rani-Borges, B., de Paiva, T.C.B., Eds.; Instituto de Biociências, Universidade de São Paulo: São Paulo, Brasil, 2022; pp. 51–65.
26. Chen, J.C.; Fang, C.; Zheng, R.; Hong, F.; Jiang, Y.; Zhang, M.; Li, Y.; Hamid, F.S.; Bo, J.; Lin, L.S. Microplastic pollution in wild commercial nekton from the South China Sea and Indian Ocean, and its implication to human health. *Mar. Environ. Res.* **2021**, *167*, 105295. [CrossRef] [PubMed]

27. Andrade, J.M.; Ferreiro, B.; López-Mahía, P.; Muniategui-Lorenzo, S. Standardization of the minimum information for publication of infrared-related data when microplastics are characterized. *Mar. Pollut. Bull.* **2020**, *154*, 111035. [CrossRef] [PubMed]
28. Koelmans, A.A.; Nor, N.H.M.; Hermsen, E.; Kooi, M.; Mintenig, S.M.; De France, J. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Res.* **2019**, *155*, 410–422. [CrossRef]
29. Rangel–Buitrago, N.; Arroyo–Olarte, H.; Trilleras, J.; Arana, V.A.; Mantilla–Barbosa, E.; Gracia, C.A.; Velez Mendoza, A.; Neal, W.J.; Williams, A.T.; Micallef, A. Microplastics pollution on Colombian Central Caribbean beaches. *Mar. Pollut. Bull.* **2021**, *170*, 112685. [CrossRef]
30. Portz, L.; Manzolli, R.P.; Herrera, G.V.; Garcia, L.L.; Villate, D.A.; Ivar do Sul, J.A. Marine litter arrived: Distribution and potential sources on an unpopulated atoll in the Seaflower Biosphere Reserve, Caribbean Sea. *Mar. Pollut. Bull.* **2020**, *157*, 111323. [CrossRef]
31. Acosta–Coley, I.; Duran–Izquierdo, M.; Rodriguez-Cavallo, E.; Mercado–Camargo, J.; Mendez–Cuadro, D.; Olivero–Verbel, J. Quantification of microplastics along the Caribbean Coastline of Colombia: Pollution profile and biological effects on Caenorhabditis elegans. *Mar. Pollut. Bull.* **2019**, *146*, 574–583. [CrossRef]
32. Garcés–Ordóñez, O.; Saldarriaga–Vélez, J.F.; Espinosa–Díaz, L.F.; Patiño, A.D.; Cusba, J.; Canals, M.; Mejía–Esquivia, K.; Fragozo–Velásquez, L.; Sáenz–Arias, S.; Córdoba–Meza, T.; et al. Microplastic pollution in water, sediments and commercial fish species from Laguna Grande de Santa Marta lagoon complex, Colombian Caribbean. *Sci. Total Environ.* **2022**, *829*, 154643. [CrossRef]
33. Watkins, L.; Sullivan, P.J.; Walter, M.T. A case study investigating temporal factors that influence microplastic concentration in streams under different treatment regimes. *Environ. Sci. Pollut. Res.* **2019**, *26*, 21797–21807. [CrossRef]
34. Kole, P.J.; Löhr, A.J.; Van Belleghem, F.G.A.J.; Ragas, A.M.J. Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1265. [CrossRef]
35. Liu, Z.; Nowack, B. Probabilistic material flow analysis and emissions modeling for five commodity plastics (PUR, ABS, PA, PC, and PMMA) as macroplastics and microplastics. *Resour. Conserv. Recycl.* **2022**, *179*, 106071. [CrossRef]
36. Welsh, B.; Aherne, J.; Paterson, A.M.; Yao, H.; McConnell, C. Spatiotemporal variability of microplastics in Muskoka-Haliburton headwater lakes, Ontario, Canada. *Environ. Earth. Sci.* **2022**, *81*, 551. [CrossRef]