Environmental Advances 8 (2022) 100236

Contents lists available at ScienceDirect

Environmental Advances

journal homepage: www.sciencedirect.com/journal/environmental-advances

Microplastics in Latin America and the Caribbean: On the adoption of reporting standards and quality assurance and quality control protocols

Jose F. Grillo [a,b], Alejandra Guerrero Rebolledo [a,b], Marcos A. Sabino [b], Ruth Ramos [a,*]

[a] Biology of Organisms Department, Centro de Estudios Ecotoxicológicos en Sistemas Marinos (CETOXMAR, Center for Ecotoxicological Studies in Marine Systems), Simón Bolívar University, Miranda 8900, Venezuela
[b] B5IDA Research Group/Chemistry Department, Simón Bolívar University, Miranda 8900, Venezuela

ARTICLE INFO

Keywords:
Microplastics
Latin America
Caribbean
Variability
Standards
Quality control

ABSTRACT

We reviewed the current status of microplastic research in Latin America and the Caribbean based on a sample of 193 papers that analyzed environmental microplastic concentration in aquatic and terrestrial ecosystems. Most of the reviewed papers were published from researchers based on Brazil, Mexico, Argentina and Chile. Overall, 63.1% of the papers studied microplastics in marine ecosystems, followed by the study of freshwater ecosystems (18.2%), estuarine (13.6%) and terrestrial environments (5.1%). Biota samples were analyzed by 40.3% of the studies, while 34.4% studied sediment samples (beach sand and submerged sediments) and 25.3% focused on water samples. Over 80% of the papers that studied microplastics in biota samples analyzed fish. There was high variability in the reported parameters employed for characterizing environmental microplastics (color, shape, and concentration units), attributed to the lack of standardized analysis guidelines for microplastic studies. Additionally, most papers adopted few quality assurance and quality control (QA/QC) protocols to avoid cross-contamination during the analytical process. At least four open access standard protocols and guidelines for microplastic analysis and monitoring programs were found since 2015, and 92% of the papers were published after said date. Nevertheless, most studies did not employ any standardized methodology for the analysis of microplastics. We recommend the adoption of a standard and QA/QC protocol for future microplastic studies in Latin America and the Caribbean to establish a cohesive baseline of microplastic data in the region and create long-term monitoring programs.

Introduction

Plastic debris pollution has been recognized as a worldwide issue in the scientific literature since the 1970s (Li et al., 2021), gaining official recognition by governments and international environmental organizations since the 1990s (Masura et al., 2015). Nevertheless, the origins of plastic pollution date back to the 1950s with the introduction of novel mass-produced plastic products that were cheap and resistant to biodegradation, expanding the use of plastics to multiple industrial and commercial applications (Geyer et al., 2017). Ever since, plastics have become an integral part of the human lifestyle in virtually all modern industries, from medical to automotive (Geyer et al., 2017), and have supported the growing rate of human expansion observed in the last few decades (Geyer et al., 2017; Li et al., 2021). More recently, the importance of plastic products has been made apparent with the COVID-19 pandemic, as the consumption of plastic personal protective equipment (e.g., face masks, gloves) and plastic packaging increased significantly (Ardusso et al., 2021; Ormaza-Gonzaìlez et al., 2021; Thiel et al., 2021). About 70-75% of the discarded plastics associated with the pandemic are estimated to turn into waste that seeps into terrestrial, freshwater, and, ultimately, marine ecosystems, causing increased economic and environmental costs (United Nations Conference on Trade and Development, 2021).

Plastic waste has been observed in terrestrial, freshwater and marine ecosystems worldwide. Nevertheless, one of the most studied ecosystems regarding plastic pollution is marine environments, which act as a sink for natural and anthropogenic terrestrial input (Ajith et al., 2020). The influence of plastic waste in marine environments is even

---

Abbreviations: MCMA, Mexico, Central America and the Caribbean region; SAPC, South American Pacific Coast region; SAAC, South American Atlantic Coast region; PCC, Polymer chemical composition; QA/QC, Quality Assurance and Quality Control.

* Corresponding author.

E-mail address: ruthr@usb.ve (R. Ramos).

https://doi.org/10.1016/j.envadv.2022.100236
Received 2 March 2022; Received in revised form 27 April 2022; Accepted 4 May 2022

recognized within the Sustainable Development Goals (SDG), in goal 14, indicator 14.1.1 (United Nations, 2018). In consequence, the study and classification systems developed for marine plastic waste have been extrapolated to other ecosystems and serve as a standard in plastic pollution studies worldwide.

Due to the fact that marine plastic pollution is heterogeneous, a classification based on size is commonly adopted to categorize plastic waste into macroplastics (1000 - 25 mm), mesoplastics (25 - 5mm), and microplastics (> 5 mm) (GESAMP, 2019). While macro and mesoplastic pollution has been associated with negatively affecting tourism (Rangel-Buitrago et al., 2018; Williams et al., 2016) and large biota like mammals (Brentano and Petry, 2020; Denuncio et al., 2011), birds (Ballejo et al., 2021; Yorio et al., 2014), and reptiles (de Carvalho et al., 2015; González Carman et al., 2014), the impact of microplastics on diverse ecosystems, in particular seas and oceans, has been the focus of interest for multiple studies worldwide.

Microplastics are defined as particles generated from thermoset or thermoplastic synthetic polymers that are smaller than 5 mm in diameter or length (GESAMP, 2019; Masura et al., 2015), with a lower size limit as small as 1 µm, although some debate still exists regarding the lower size range of microplastics (GESAMP, 2019). According to their origin, microplastics are classified as either primary or secondary. Primary microplastics include materials designed for particular uses in consumer products or industrial applications, which tend to comprise small pellets or resin (nurdles) employed as a precursor of plastic products (Ajith et al., 2020; GESAMP, 2019). Secondary microplastics result from chemical (photolysis), physical (erosion), or biological (enzymatic action) degradative processes, typically described for marine or aquatic ecosystems, that affect environmental macroplastics or mesoplastics (Li et al., 2021), promoting their fragmentation.

Various facets of microplastic pollution in marine or aquatic environments have been explored worldwide, including the potential toxicity (Araújo and Malafaia, 2020; Baeza et al., 2020; Brennecke et al., 2015) and remediation techniques (Narciso-Ortiz et al., 2020) of microplastics. However, one of the most common objectives of the published papers is the study of microplastic environmental abundance in water, sediment, and biota samples (Ajith et al., 2020), with few papers focusing on quantifying microplastic abundance on polar ecosystems (i.e., glaciers, snow) or airborne microplastic abundance in natural environments (Luo et al., 2022; Zhang et al., 2022). In addition, reports on microplastic studies are usually characterized by a lack of standard sampling protocols and sample analysis (Ajith et al., 2020; Kutralam-Muniasamy et al., 2020a; Luo et al., 2022; Zhang et al., 2022). As a consequence, several studies have resorted to creating customized processing protocols to report microplastic environmental abundance, which causes the results of different papers with similar objectives not to be directly comparable due to methodological differences (Ajith et al., 2020).

Interestingly, most of the microplastic studies are published in international scientific journals outside of South America and the Caribbean: by 2020 approximately 86% of the papers were published by researchers studying microplastics in Europe, Asia, and North America (Ajith et al., 2020). Kutralam-Muniasamy et al. (2020a) previously reviewed the research trends in papers that studied the environmental abundance of microplastics and were published in Latin American countries, in order to establish a regional baseline for future papers in the region. Nevertheless, the use of diverse methodologies prevented a direct comparison of the results published in Latin American papers (Kutralam-Muniasamy et al., 2020a), similar to the previous report made for the worldwide status of microplastic research (Ajith et al., 2020).

At present time, 2022, there is no microplastic legislation available for any country of Latin America and the Caribbean, which may be related to the lack of long-term monitoring programs that aid in the establishment of regulations. However at least 27 countries of the region present national or local legislations that aim to reduce, prohibit, and/or eliminate single-use plastics (United Nations Environment Programme, 2021). Furthermore, a novel, legally binding resolution that aims to tackle the full life cycle of plastic pollution, from manufacturing to disposal in all of the signing countries has been proposed at the fifth session of the United Nations Environment Assembly (EA.5/L.23). As legislation continues to advance, the establishment of baselines and long-term microplastic monitoring data is needed to aid in the development of accurate plastic and microplastic pollution regulations.

The objective of this review was to summarize the current status of studies published in Latin America and the Caribbean that perform environmental microplastic determinations across the water, sediment, or biota samples in aquatic (including polar environments) and terrestrial ecosystems. Furthermore, we evaluated the sources of variability among the results of the reviewed papers and proposed standard sampling and analysis guidelines and quality assurance and quality control (QA/QC) protocols to be adopted for future studies in the region. Finally, we emphasized the importance of moving towards the development of long-term monitoring programs at a regional level to help to develop regulations for the management of microplastic pollution.

Methods

An extensive scientific literature search was performed in the search engine Google Scholar during the months of April and December 2021 respectively. The search criteria included the retrieval of articles published from the year 2010 to 2021 from the following countries: Mexico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Aruba, Curaçao, Trinidad and Tobago, Grenada, Saint Vincent and the Grenadines, Saint Lucia, Martinique, Dominica, Guadeloupe, Montserrat, Antigua and Barbuda, Saint Kitts and Nevis, Anguilla, British Virgin Islands, US Virgin Islands, Puerto Rico, Dominican Republic, Haiti, Jamaica, Cayman Islands, Cuba, Bahamas, Ecuador, Peru, Bolivia, Chile, Argentina, Uruguay, Paraguay, Brazil, French Guiana, Suriname and Guyana. The search terms employed were: "microplastics", "AND", the country name from the provided list, "Microplásticos", "AND", the country name from the provided list, as the search was carried out in both English and Spanish.

A total of 292 papers were found after the initial search. Two hundred and twenty-one papers studied microplastics while 71 papers analyzed macroplastics, which were beyond the scope of this review and thus were omitted. From the remaining 221 articles, only those that were published in journals indexed in Latindex, SCOPUS, SCI and/or SCI (E) were included in the analysis.

Diverse objectives were studied in the microplastics papers, including the characterization of the bacterial biofilm community (Pazos et al., 2020; Silva et al., 2019), evaluation of the presence of microplastics in edible commercial goods (e.g., milk, water) (Kutralam-Muniasamy et al., 2020b; Mason et al., 2018), modelling microplastic aquatic dynamics (degradation, transport) (Gorman et al., 2020), or determining microplastic concentration in wastewater (Sierra et al., 2020). Nevertheless, as the objective of this review was to analyze the published papers that assessed microplastic concentration in water, sediments or biota samples from terrestrial or aquatic (marine, freshwater, polar or estuarine) environments, only 193 papers were selected. Table S1 has a full list of the reviewed papers in this study.

The information retrieved from the reviewed papers by two independent readers was classified into 19 different variables that encompass the paper's metadata and experimental information, including sampling methods and results (Table S2). Summary statistics were calculated from the retrieved data. All data analysis procedures (exploratory data analysis, summary statistics and data visualization) were performed in the R statistical software using the RStudio graphical interface (R Core Team, 2021). The R packages employed throughout the analyses were: tidyverse (version 1.3.1) (Wickham et al., 2019), patchwork (version 1.1.1) (Pedersen, 2020), sf (version 1.0-6) (Pebesma, 2018), rnaturalearth (version 0.1.0) (South, 2017a), rnaturalearthdata (version 0.1.0) (South, 2017b), rgeos (version 0.5-9) (Bivand and Rundel, 2021) and ggtext (version 0.1.1) (Wilke, 2020).

Status of microplastic research in Latin America and the Caribbean

Geographic distribution of the reviewed articles

The 193 reviewed papers on microplastics were grouped into 3 geographical regions based on their access to the Caribbean Sea, and the Pacific and Atlantic Oceans: Mexico, Central America and the Caribbean (MCAC), the South American Pacific Coast (SAPC), including Bolivia, and the South American Atlantic Coast (SAAC), including Paraguay. For each region the papers were further classified according to the country they were published in (Fig. 1). Table S3 presents the sampling sites of the papers that included GPS coordinates, while Table S4 includes the number of papers by country and the type of sample that was analyzed (water, sediment, biota).

Overall, the SAAC presented the highest number of published papers (52.8%, n = 193), followed by the MCAC (30.1%, n = 193) and, lastly, the SAPC (17.1%, n = 193), with Brazil, Chile and Mexico (and Colombia for the Caribbean sub-region) producing the highest research output for each region (Fig. 1). Brazil was the country with the earliest international microplastic publications (2010), while it also presented the highest number of published papers (32.7%, n = 202, including papers that studied multiple countries). Furthermore, the Goiana estuary, located in Brazil, presented the highest number of papers on microplastics focused on a single sampling location from Latin America and the Caribbean (8 studies, n = 193).

As Brazil was the country with the highest number of papers on microplastics for Latin America and the Caribbean and it also presents the highest percentage of gross domestic product destined for science, technology and innovation, the relationship between the percentage of gross domestic product (UNESCO Institute for Statistics, 2022) and microplastic research output from 2010 to 2018 was investigated. Nevertheless, even though approximately 75% of the microplastic articles published by most countries present public funding (either through grants or affiliations to public universities), the percentage of gross domestic product does not seem to correlate to the research output of other Latin American countries (Fig. S1). Other socioeconomical factors such as international funding opportunities and cooperation programs or incentives may be related to the observed research output of different countries, highlighting the heterogeneous status of microplastic research in Latin America and the Caribbean.

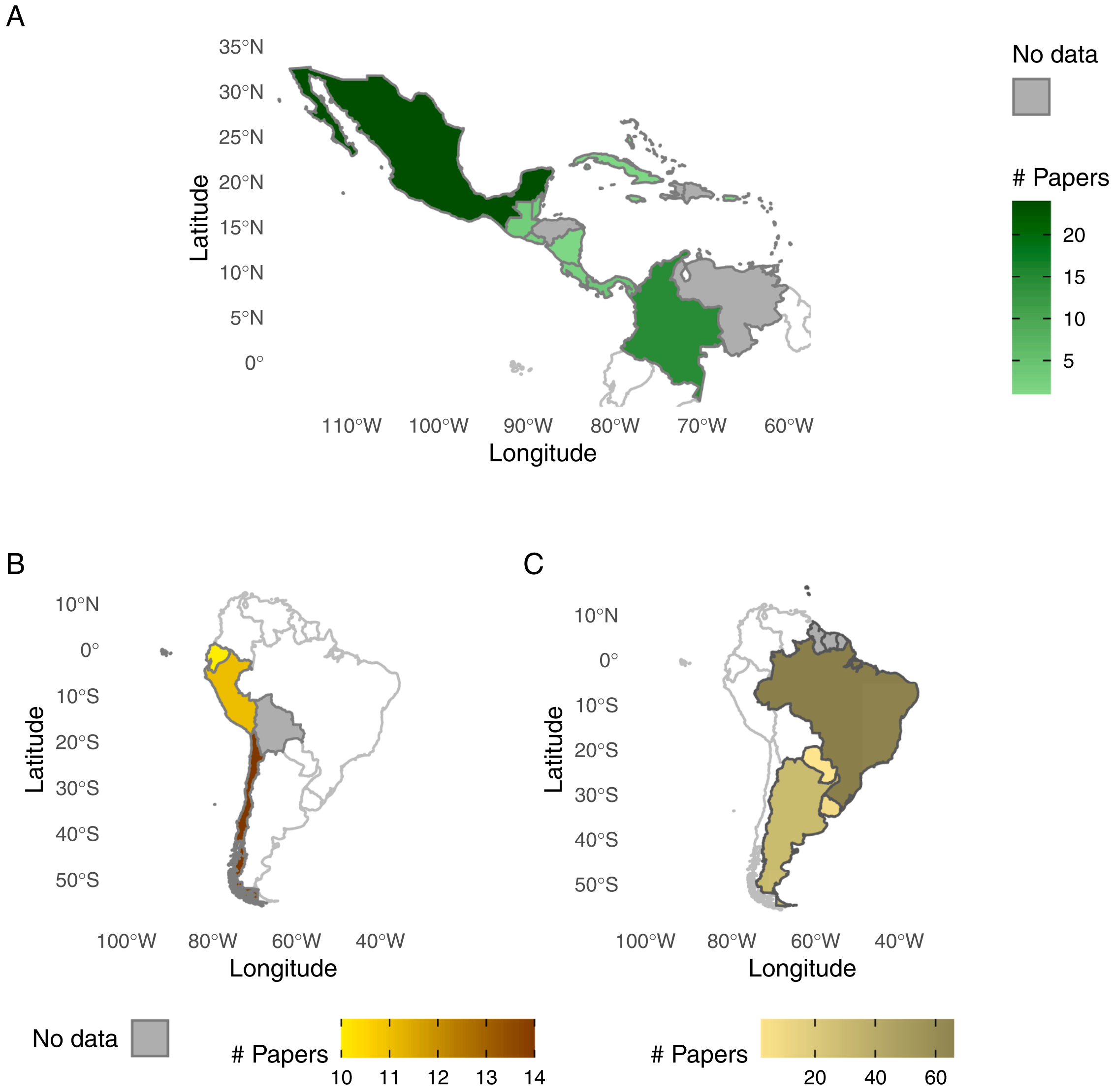

Fig. 1. Geographical distribution of the reviewed papers. A. Mexico, Central America and the Caribbean region (MCAC). B. South American Atlantic Coast region (SAAC). C. South American Pacific Coast region (SAPC).

Microplastics in aquatic and terrestrial ecosystems

The reviewed papers were classified further by the environment they studied (marine, freshwater, estuarine, or terrestrial) and the type of collected sample (water, sediment, biota) (Fig. 2). While most studies analyzed microplastics isolated from one type of sample in one environment, some papers examined multiple types of samples (e.g., Water and sediment samples from one ecosystem) (Costa et al., 2019; Martínez Silva and Nanny, 2020; Ríos et al., 2020), and different kinds of environments (marine and freshwater sampling points) (Borges Ramirez et al., 2019; Narciso-Ortiz et al., 2020) or a combination of these variables (e.g., water and sediment samples taken from marine and freshwater environments). In consequence, the total number of papers employed for comparing the types of samples or the different environments was 198 and 221, respectively, which accounts for the duplication of studies that aligned with more than one category of the analysis. Additionally, 6.7% of the papers (n = 193) studied the adsorbed concentration of organic (e.g., hydrocarbons) or inorganic (e.g., heavy metals) pollutants of the microplastic samples. However, these interactions were not further analyzed in this review.

Terrestrial environments were studied by 5.1% of the papers (n = 198), making it the least studied ecosystem, followed by estuarine (13.6%, n = 198) and freshwater ecosystems (18.2%, n = 198), with the latter presenting studies that were carried out mostly on rivers (Fig. 2A). Over half of the reviewed papers (63.1%, n = 198) were concerned with determining microplastic concentrations in marine ecosystems, a trend that has been highlighted in a previous study for the Latin American region (Kutralam-Muniasamy et al., 2020a). Estuarine microplastic studies were predominantly performed in the SAAC, making up 13.7% of the papers from said region (n = 102 for the SAAC region), with most of the papers being published by Brazilian authors.

Estuarine environments are regarded as one of the main entry pathways of terrestrial and freshwater microplastics to marine ecosystems (Ajith et al., 2020; United Nations Environment Programme, 2020). Additionally, estuaries are highly dynamic environments with salinity and water dynamic fluctuations that may affect the dispersal of microplastics due to the associated changes in water density (Ajith et al., 2020; GESAMP, 2019; Kutralam-Muniasamy et al., 2020a). Consequently, more studies are needed to elucidate the effect of estuaries on the dispersion of microplastics.

Only 1 paper analyzed microplastic abundance in snow samples from the Antisana glacier, a high-altitude polar region located in Ecuador (Cabrera et al., 2020), which was classified as a freshwater study for the purpose of the analysis. As evidenced by this result, more studies that evaluate microplastic abundance and dynamics on the polar ecosystems of Latin America, represented by the Andean Mountain range, are needed to fill the large gaps of knowledge identified in this review.

Future studies that evaluate microplastic environmental determinations in Latin America and the Caribbean should expand the current knowledge of underrepresented ecosystems like terrestrial or polar environments, while diversifying the research questions of better studied ecosystems (e.g., marine ecosystems) in order to establish a solid baseline of information.

Microplastics in different environmental matrices

Only three types of samples were considered for evaluating microplastic environmental concentrations in marine, freshwater or terrestrial ecosystems: water (including 1 article that studied microplastics in snow samples), sediment or biota.

Water and sediment samples

Water samples were analyzed in 25.3% of the papers (n = 221, considering the papers analyzing different types of samples) (Fig. 2B) and they mostly focused on sampling surface water, as few papers analyzed water column samples (Quesadas-Rojas et al., 2021; Rodríguez Chialanza et al., 2018; Sánchez-Hernández et al., 2021). On the other hand, sediment samples, which included aquatic shoreline

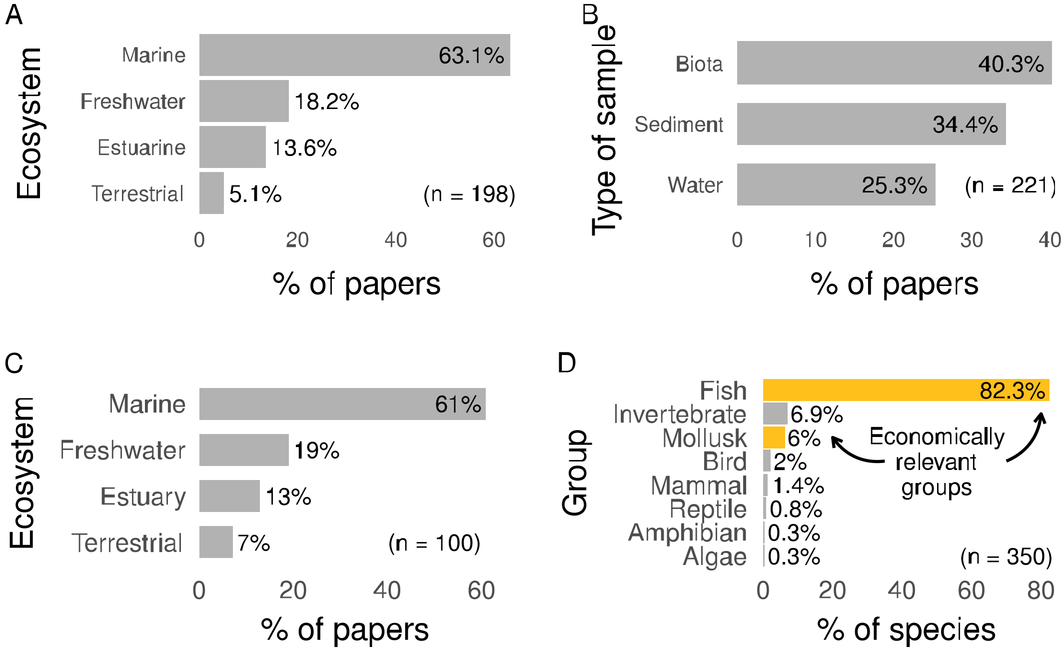

Fig. 2. Scope of the reviewed papers. A. Papers were grouped by 4 ecosystems: marine, freshwater, estuarine or terrestrial, with marine environments being studied by most papers (63.1%, n = 198 considering papers that studied more than one ecosystem). B. Papers were grouped by the type of analyzed sample, with biota samples being the most frequent (40.3%, n = 221 considering the papers that analyzed more than one type of sample). C. Papers that studied microplastics in biota were grouped according to the ecosystem where the biota samples were taken. Over half of the papers studied marine species (61%, n = 100 papers considering the papers that studied species from different ecosystems). D. Species were separated according to a general taxonomic classification that considered eight classes. Fishes were the most frequent species analyzed by the papers that studied biota samples, with 82.3% of the total species belonging to said group (n = 350 species). Fish and mollusks were considered the main economically relevant groups in the analysis.

sediments (e.g., beach sand), submerged sediments, and some terrestrial soil samples (Álvarez-Lopeztello et al., 2021; Corradini et al., 2021, 2019; Ramos et al., 2015), were taken in 34.4% of the reviewed papers (n = 221) (Fig. 2B). There were regional differences in the number of papers on microplastics that analyzed different ecosystems and types of samples that are further detailed in Table S5.

With regards to the reported sampling methods, most studies employed manta trawls or equivalent devices (e.g., plankton meshes, neuston net) for taking surface water samples, while water column samples were taken using grab samplers (e.g., Niskin or Nasen bottles). The usual sampling strategy for sediment samples included the use of transects and quadrats for aquatic shoreline sediments, Van Veen samplers for submerged superficial sediments, and soil core samplers for terrestrial sediments.

As vital elements of ecosystems, water and sediments play key roles on the environmental dynamics of microplastics. In consequence, the inclusion of water and sediment samples in future studies on microplastic abundance in Latin America and the Caribbean is needed to elucidate sources, sinks and long-term dynamics of microplastics in different ecosystems through routine monitoring programs. In the section: Emphasis on variability we discuss the high variability observed in the characterization of microplastic samples isolated from water and sediment samples and in the section: Available standards we propose the adoption of a standard to address the previously described heterogeneity issue.

Biota samples

The presence of environmental microplastics on biota samples were analyzed by the majority of the reviewed papers (40.3%, n = 221, considering the papers that analyzed different types of samples) (Fig. 2B), as they were the most frequent type of sample taken in freshwater, estuarine and terrestrial ecosystems, only falling behind to sediment samples in marine ecosystems (Table S5). The analysis of microplastics in biota samples was performed across 350 different marine, freshwater, terrestrial, and estuarine species in a total of 89 papers, with most studies analyzing the digestive tract (or equivalent organs) of the sampled individuals (59.8%, n = 97 considering the papers that studied more than 1 tissue).

The reported species were grouped according to their ecosystem (terrestrial, marine, freshwater, or estuarine) and general characteristics (fish, invertebrates, mollusks, birds, mammals, reptiles, amphibians, and algae). As mollusks are considered an economically relevant group, they were not included with the other invertebrates. Estuarine species were validated based on the listed environments on FishBase (Froese and Pauly, 2021) or WoRMS (WoRMS Editorial Board, 2022) and the studied ecosystem specified by the respective reviewed paper.

Overall, 93% of the reviewed biota papers (n = 100 considering the papers that analyzed biota samples from multiple ecosystems) studied microplastic interactions with aquatic species (marine, freshwater, or estuarine biota), while only 7% (n = 100) analyzed terrestrial species (Fig. 2C). Over 82% of the studied species (n = 350) were fishes, followed by invertebrates with 6.9% (n = 350) and mollusks with (6%, n = 350), while few studies sampled organisms from the other groups (mammals, birds, amphibians, reptiles or algae) for microplastic analysis, regardless of the sampled ecosystem (Fig. 2D). Notably, 98.8% of the species studied in estuaries (n = 80) were fishes, highlighting the importance of this group for microplastic studies in Latin America and the Caribbean.

The most frequently studied species was *Mugil curema*, which was included in 7.9% of the reviewed biota papers (n = 89), followed by *Prochilodus lineatus* (5.6%, n = 89), *Caranx hippos* (4.5%, n = 89), *Mugil cephalus* (4.5%, n = 89) and *Oreochromis niloticus* (4.5%, n = 89). Most of these economically relevant species present wide geographical distributions, evidenced by their inclusion in studies from 2 different regions from Latin America and the Caribbean (Nunes et al., 2021; Salazar-Pérez et al., 2021), which makes them potentially valuable bioindicators for microplastic studies in Latin America and the Caribbean. Table S6 contains the list of the 350 species reported by the 89 reviewed papers.

The high number of biota samples in the reviewed papers may be associated with determining microplastic toxicity in aquatic or terrestrial organisms, one of the main concerns of microplastic pollution (GESAMP, 2019; United Nations Environment Programme, 2020). Current reports of microplastic toxicity in different organisms are varied, ranging from no apparent toxic effects (Castro et al., 2020; Grillo et al., 2021; Opitz et al., 2021) and moderate effects (e.g., altered metabolic rates or behavior) (Carrasco et al., 2019; da Costa Araújo and Malafaia, 2021) to severe effects like genotoxicity or tissue damage (da Costa Araújo et al., 2020; Détrée and Gallardo-Escárate, 2017). However, there is still some debate on identifying the specific characteristics of microplastics that produce the toxic effects, as environmental microplastics have diverse microbial communities and adsorbed pollutants that may affect their toxicity (Gorman et al., 2019; Pazos et al., 2020; Pelamatti et al., 2019). Furthermore, the study of the toxicity associated with environmental microplastics can provide clues to the potential toxicity that microplastics may cause to humans, a novel research topic that is rapidly gaining attention for reports of microplastic presence in human feces (Ibrahim et al., 2021), placenta (Braun et al., 2021), lung tissue (Jenner et al., 2022) and blood (Leslie et al., 2022).

Fishes and mollusks are recognized as economically relevant organisms worldwide (Fig. 2D), evidenced by their high human consumption, which fuels the diverse industries (e.g., fisheries) and the economy of countries like Peru and Chile (FAO, 2022a, 2022b; Pozo et al., 2019). Working with economically relevant species implies unique sampling opportunities, such as the analysis of commercially acquired organisms (e.g., purchased in stores or directly from fisher) employed by 6.7% of the papers (n = 89) (Bermúdez-Guzmán et al., 2020; Borges-Ramírez et al., 2020; Calderon et al., 2019; De-la-Torre et al., 2019; Iannacone et al., 2021; Nunes et al., 2021), that are unavailable for water or sediment samples. Nevertheless, appropriate QA/QC protocols should be adopted when analyzing commercially acquired organisms, as there is a higher potential for cross-contamination during the sampling process that may produce uncertainty in the reported microplastic concentrations (See Section: QA/QC for contamination control).

Emphasis on variability

As stated by previous studies, there was a high heterogeneity in the results of the reviewed papers (Ajith et al., 2020; Kutralam-Muniasamy et al., 2020a; Prata et al., 2021). The observed variability was attributed to 3 main factors: the omission of commonly reported parameters, the use of redundant categories for each parameter, and the lack of standardized sampling and reporting protocols. Commonly employed parameters like microplastic shape, color, and polymer chemical composition (PCC) were missing in 7.3%, 37.3%, and 51.8% of the reviewed papers (n = 193), respectively.

The use of unique or redundant categories for microplastics characterization was reflected in the analysis of four shared parameters: microplastic shape, color, PCC, and environmental concentration units (units) (Fig. 3). Over 55 different categories were employed for each parameter; however, most of them are interchangeable, as reports of microplastic threads, filaments, or fibers can be grouped under a single category, while a report of microplastics L^{-1} is equivalent to items L^{-1} for most studies. Most papers lack a clear definition of the employed classifications for each parameter, which creates uncertainty when trying to compare results obtained from different studies, even when similar sampling methodologies are employed. The use of highly specific categories for reporting microplastic characteristics is also ill-advised, as reports of detailed microplastics units associated with a specific species or unique sampling location cannot be easily compared to other studies.

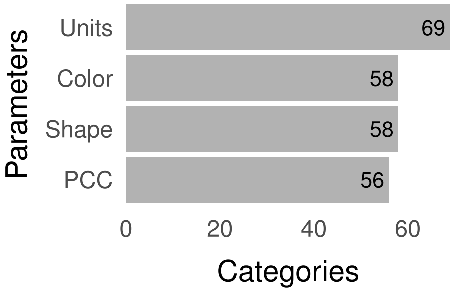

Fig. 3. Number of categories reported for each parameter employed for characterizing environmental microplastics. PCC: Polymer Chemical Composition. For each of the considered parameters reported by 193 papers, the number of single categories was counted (e.g., for the microplastic shape, the categories might include fibers, filaments fragments, pellets, spheres, etc.).

Additional sources of variability include reports of ambiguous categories like color hues (e.g., blue and light blue) and the inclusion of natural or synthetic polymers (e.g., rayon, latex, or cellulose) when reporting microplastic PCC. Even though this review only analyzed four parameters commonly employed in microplastic studies, the observed trends are expected to be present in parameters not considered in Fig. 3, such as microplastic size.

Generally, environmental pollution studies tend to report a set of parameters that characterize pollutants, which include their chemical composition, concentration, and physicochemical properties, along with environmental parameters relevant to the sampling ecosystem (e.g., temperature, pH) (GESAMP, 2019). There is, however, no consensus in the reviewed papers on a set of universally adopted parameters to be used in the characterization of environmental microplastics, as different papers reported different parameters. Nevertheless, the shape, color, and PCC of microplastics constitute some of the basic parameters that should be included in all microplastic environmental studies, as they provide valuable information for the creation of local or regional microplastic pollution baselines, and they can be analyzed at a relatively low cost (GESAMP, 2019; González et al., 2016). Microplastic shape and color can be analyzed with light microscopy, while microplastic PCC can be obtained via FT-IR or Raman spectroscopy, the main characterization techniques employed for reporting microplastic polymers (Alvarez-Zeferino et al., 2020; GESAMP, 2019; González et al., 2016; Kutralam-Muniasamy et al., 2020a; Montecinos et al., 2021; Truchet et al., 2021).

While researchers are encouraged to clearly define the categories they employ for reporting different microplastic characteristics, the use of standardized categories, as well as the inclusion of a set of minimum reporting parameters and protocols, are required to address the poor comparability found in the reviewed papers. However, it is recognized that the analysis of certain parameters may exceed the budget of some studies, which could explain the percentage of papers that did not report microplastic PCC (51.8%, n = 193). In the section: Available standards, we review some currently available standard protocols and propose the adoption of a robust methodology for future studies in Latin American and Caribbean countries.

Available standards

A common statement found throughout the revision of the selected papers, regardless of their publishing date, was the need for standard protocols that specify sampling and analysis procedures for microplastic studies, including guidelines for reporting the experimental results (Ajith et al., 2020; Kutralam-Muniasamy et al., 2020a). The lack of standardization in the field of microplastics studies is regularly referenced when employing methodologies that produce unique microplastic concentration units, or the use of unique categories for reporting microplastic characteristics (See section: Emphasis on variability) (Cabrera et al., 2020; Gimiliani et al., 2020). In order to review the current state of microplastic standard protocols, we selected four currently available standards: two standards for marine and freshwater ecosystems, respectively, that were published since 2015 and had open access status, and we compared their guidelines with the reviewed papers.

The chosen standards for marine environments were Masura et al. (2015), published by the U.S. National Oceanic and Atmospheric Administration (NOAA), and the guidelines published by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (GESAMP, 2019). For studies of microplastics found in freshwater environments, the standards published by the European Union (González et al., 2016) and by the United Nations Environment Programme (UNEP) (United Nations Environment Programme, 2020) were selected.

Approximately 92% of the reviewed papers were published after Masura et al. (2015), the standard with the earliest publishing date considered for this review (Fig. 4). This result contrasts with the widespread claims made about the lack of standardized analysis and reporting guidelines in the microplastic field of study. Moreover, comprehensive standards and guidelines have been published in the past few years, such as GESAMP (2019) and UNEP (2020), and, at the time of this study, multiple guidelines are being developed by the International Organization for Standardization (ISO) (e.g., ISO/AWI 5667-27 and ISO/DIS 24187) and the American Society for Testing and Materials (ASTM International) (e.g., ASTM WK72349, ASTM WK74436, ASTM WK70831 and ASTM WK67788). Additionally, an updated version of the Guidance on Monitoring of Marine Litter in European Seas (European Commission et al., 2013) is under preparation. As such, Fig. 4 suggests that Latin American and Caribbean authors are unfamiliar with the currently available standardized protocols for microplastic studies.

Comparison of available standards

Table 1 summarizes the scope of the chosen standards and the outlined guidelines for the analysis of five common parameters reported in microplastic studies: microplastic shape, color, size, environmental concentration units (units), and detection limit of the analytical techniques.

All of the selected standards provide guidelines for the analysis of microplastics isolated from water and sediment samples; however, the standards tend to focus on either establishing monitoring programs (GESAMP, 2019; González et al., 2016; United Nations Environment

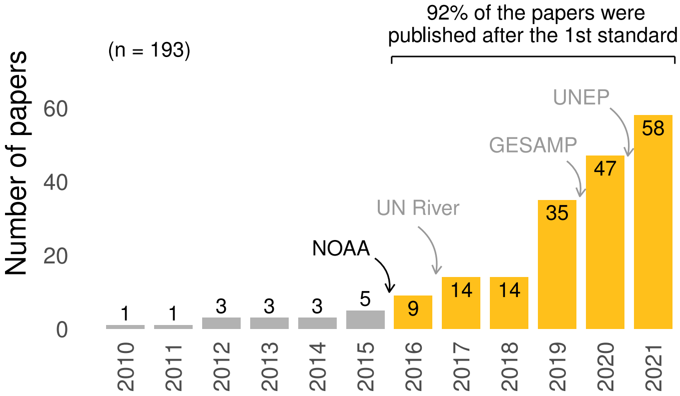

Fig. 4. Publishing year of the reviewed papers and the chosen standards. The number of papers has increased with each passing year. Additionally, most of the reviewed papers (92%, n = 193 papers) were published after the first standard analyzed in this paper was made available. NOAA: Masura et al, (2015), UN River: González et al. (2016), GESAMP: GESAMP (2019), UNEP: United Nations Environment Programme (2020).

Table 1
Summary of the selected standards. The standards were classified according to their scope (ecosystem and the types of samples) and five parameters commonly employed for describing environmental microplastics: microplastic shape, color, size (reported in categories), concentration units, and detection limit.

Publishing organization	Ecosystem	Type of sample	Shape	Color	Size class	Units	Detection limit	Reference
NOAA	Marine	Water	Hard plastics, Soft plastics (Foam), Film, Line, Fiber, Sheet	-	(5600 - 1000) μm, (1000 - 300 μm)	grams microplastics/ mL matrix	335 μm	Masura et al. (2015)
		Sediment	Hard plastics, Soft plastics (Foam), Film, Line, Fiber, Sheet	-	(5000 - 1000) μm, (1000 - 300) μm	grams microplastics/ grams total solids, grams microplastics/ m^2 matrix	300 μm	
GESAMP	Marine	Water	Fragment, Foam, Film, Line, Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	(5000 - 1000) μm, (1000 - 300) μm, (300 - 20) μm	Microplastic number/ m, Microplastic number / L, Microplastic number / m^3, Microplastic grams / m, Microplastic grams / L, Microplastic grams / m^3	100 μm (visual inspection), 20 μm (FT-IR)	GESAMP, 2019
		Sediment	Fragment, Foam, Film, Line, Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	(5000 - 2000) μm, (2000 - 1000) μm, (1000 - 500) μm, (500 - 250) μm	Microplastic number /m^2, Microplastic number / m^3, Microplastic grams/ m^2, Microplastic grams/ L, Microplastic grams/ m^3	100 μm (visual inspection), 20 μm (FT-IR)	
		Biota	Fragment, Foam, Film, Line, Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	(Suggests other protocols including NOOA)	(Suggests other protocols including NOOA)	(Suggests other protocols including NOOA)	
UNEP	Freshwater	Water	Fragment Foam Film Fiber Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	(5000 - 500) μm, < 500 μm	item counts/ volume, item mass/volume	Operationally defined (Mesh pore size)	United Nations Environment Programme (2020)

(continued on next page)

Table 1 (*continued*)

Publishing organization	Ecosystem	Type of sample	Shape	Color	Size class	Units	Detection limit	Reference
		Sediment	Fragment Foam Film Fiber Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	(5000 - 500) µm, (500 - 100) µm,(100 - 50) µm,(50 - 10) µm	item counts/ volume, item mass/volume	Operationally defined (Sieve pore size)	
		Biota	Fragment Foam Film Fiber Pellet	Pink, Red, Orange, Brown, Yellow, Olive, Yellow-Green, Green, Blue, Purple, White, Gray, Black	Not specified	Not specified	Not specified	
European Commission	Freshwater	Water	Fragment, Foil, Fiber, Foam, Pellet	-	(5000 - 0.333) µm	item number/time, item weight/ time, item number/volume, item weight/ volume	Operationally defined (Mesh pore size)	
		Sediment	Fragment, Foil, Fiber, Foam, Pellet	-	(5000 - 0.333) µm	item number/volume, item weight/volume, item number/area, item weight/area	Operationally defined (Sieve pore size)	

Programme, 2020) or creating detailed laboratory protocols (Masura et al., 2015). Three out of four standards, with the exception of Masura et al. (2015), recommend reporting environmental microplastic concentration as both microplastic counts and mass in recognition of the different information that can be interpreted from these different units in the context of monitoring programs and regulatory legislation. Furthermore, GESAMP (2019) and United Nations Environment Programme (2020) provide additional recommendations for sampling and analyzing microplastics in biota, although the specified guidelines were not as complete as those for water and sediment samples.

The standards designed for marine microplastic studies provided more information for the chosen parameters than freshwater standards (Table 1). However, the suggestions provided by both freshwater and marine standards have the potential to be used for either environment with few modifications needed to the sampling protocols (GESAMP, 2019; United Nations Environment Programme, 2020), as the different standards often reference each other when providing sampling or analysis guidelines. Overall, GESAMP (2019) was the most robust standard with regards to the guidelines proposed for the chosen parameters employed for the characterization of microplastics isolated from all types of samples: water, sediment, and biota.

The parameters analyzed in Table 1, along with microplastic PCC, constitute the minimum set of reporting parameters proposed for papers that analyze microplastic environmental concentration (GESAMP, 2019; González et al., 2016; United Nations Environment Programme, 2020). The information provided by the joint analysis of these parameters could aid in the development of long-term monitoring programs, regulatory legislation, or environmental risk assessment studies, which are urgently needed in the field of microplastic pollution (GESAMP, 2019; González et al., 2016; Kutralam-Muniasamy et al., 2020a; United Nations Environment Programme, 2020).

However, the omission of some parameters from some studies noted in the section: Emphasis on variability should be avoided, when possible, as each parameter usually entails information relevant for multiple applications. As an example, the color of microplastics has been proposed as a factor that determines the ingestion of the pollutant by biota that relies on visual cues for feeding (Chen et al., 2020; GESAMP, 2019; Ryan et al., 2019; Xiong et al., 2019), although more research is needed to elucidate said relationship. Furthermore, as the polymers employed for the creation of microplastics are transparent, the addition of dyes (employed for polycarbonates) or pigments (employed with polyolefins) that are associated with metallic compounds (e.g., ZnO for white, Cobalt II diacetate (Co) for blue, mixtures of CdS and CdSe for red or orange) have the potential to leach into the environment, enhancing microplastic toxicity (Bandow et al., 2017; Liu et al., 2020; Turner and Filella, 2021).

Finally, reporting the detection limit of the analytical techniques increases the reproducibility and comparability of the results, while also adhering to general quality assurance and quality control (QA/QC) practices.

Recommendation of a regional standard

The flexibility of GESAMP (2019) was noted when comparing the standards with the reviewed papers that studied water or sediment samples, as the suggested guidelines could be adapted to a higher percentage of published papers when compared to the other standards. All of the reviewed papers included at least one classification for reporting the shape of microplastics, while 58.1% employed the recommended microplastic concentration units present in GESAMP (2019), the highest percentages obtained for any standard (Table S7). Additionally, 22.6% and 10.8% of the papers employed the proposed guidelines by both GESAMP (2019) and Masura et al. (2015) for classifying microplastic size and establishing a detection limit, respectively (Table S7). While the reviewed papers used different sampling protocols from those proposed by the standards, the guidelines outlined by GESAMP (2019) have the greatest potential to recover the most information of the currently published papers.

Overall, GESAMP (2019) was considered as the best option for the adoption of a regional standard for studies that measure microplastic pollution in marine environments, both for water and sediment samples. Furthermore, while the standard published by the United Nations Environment Programme (2020) was regarded as the recommended standard for freshwater microplastic studies, any missing information from the said standard should be supplemented with GESAMP (2019). Even though both standards also provide guidelines for analyzing biota samples, they should be supplemented with more specific sampling and processing protocols for the specific taxonomic group that is being studied.

Ultimately, the current goal of microplastic research is to create local and regional long-term monitoring programs. However, for their correct execution, environmental microplastic results need to include a set of clearly defined variables and classifications that enable the harmonization of the data to facilitate modeling studies destined to aid in the development of regulatory legislation. To that effect, most of the reviewed guidelines in this paper tend to focus on establishing monitoring programs in either marine or freshwater environments (GESAMP, 2019; González et al., 2016; United Nations Environment Programme, 2020), suggesting that the provided guidelines can be adapted to multiple environments and current on-going monitoring programs in order to create a cohesive baseline for Latin American and the Caribbean.

QA/QC for contamination control

Environmental pollution studies rely on standards of quality assurance and quality control (QA/QC) that certify that the reported results are a reliable estimate of the concentration of a pollutant in any ecosystem through measures like precision and accuracy (Prata et al., 2021; Wagner, 1995). In order to achieve acceptable QA/QC values, the sampling and analysis protocols of environmental pollutants need to take into account the influence of cross-contamination at any point of the analysis and its effect on the reproducibility of the results (Prata et al., 2021; Wagner, 1995; Ziajahromi and Leusch, 2022).

However, there is a current lack of widely adopted QA/QC guidelines for microplastic studies (Brander et al., 2020; Connors, 2017; Prata et al., 2021), similar to the reported absence of standard sampling and analysis protocols (See section: Available standards). As microplastic contamination has been reported in virtually all environments, including indoor spaces, like laboratories and households (Brander et al., 2020; Prata et al., 2021), the adoption of robust QA/QC protocols is required to avoid sample contamination throughout the laboratory microplastic analysis. This section evaluates the current state of QA/QC guidelines (focusing on contamination control measures) in microplastic studies by comparing the ten contamination control procedures proposed by Prata et al. (2021) to the reviewed papers.

Specific QA/QC strategies for microplastic toxicity bioassays have been proposed to harmonize the published information for the eventual development of environmental risk assessments (Connors, 2017; de Ruijter et al., 2020). Briefly, the guidelines address the environmental relevance of the study, its experimental design, and the use of appropriate endpoints of the bioassay. As the study of experimental papers on microplastics (e.g., toxicity bioassays) is beyond the scope of this review, the reader is encouraged to read the papers by Connors et al. (2017) and de Ruijter et al. (2020) for further information.

Selected QA/QC guidelines

Prata et al. (2021) proposed a set of ten guidelines that address multiple contamination sources found throughout the sampling and analysis stages of microplastic studies. Briefly, the proposed measures include: using cotton clothing, exclusively using glass or metal laboratory equipment, appropriately cleaning the laboratory equipment before and after its use, filtering all working solutions, minimizing sample exposure time to the laboratory conditions, processing the samples in controlled-air conditions, cleaning the filters before their use, using blanks throughout the analysis procedure, using controls (exposed filters) to account for airborne contamination, and washing the laboratory equipment between the analysis of each sample (Prata et al., 2021). Table S8 shows a more detailed description of the contamination control protocols, along with suggestions outlined by Brander et al. (2020). For further information, the reader is encouraged to read the original paper (Prata et al., 2021).

The guidelines proposed by Prata et al. (2021) were found to be the most robust in comparison to the QA/QC suggestions included in standard protocols (Section: Available standards), as Prata et al. (2021) formulated clear actions that address contamination sources that were missing in the other protocols. As an example, the use of sampling and analysis blanks is separated from the use of airborne contamination controls, such as the use of exposed filter papers close to the working areas (Prata et al., 2021), as the information provided by each procedure is different, yet complementary. However, earlier standards only suggest avoiding the use of plastic equipment and clothing (Masura et al., 2015).

The detailed nature of the protocols proposed by Prata et al. (2021), ensure that researchers are able to control cross-contamination and identify the steps in the sampling or analysis workflow that has the greatest risk of contaminating the sample. As such, they are considered as one of the most thorough contamination control protocols available that hold an experimentally validated high QA/QC standard in microplastic research.

Status of QA/QC protocols in Latin America and the Caribbean

Overall, 38.9% of the reviewed papers (n = 193) do not specify the use of any of the ten contamination control protocols proposed by Prata et al. (2021); however, the majority of those papers presented earlier publication dates than 2021 (Fig. 5). Nevertheless, the use of contamination control protocols has increased in recent years, as evidenced in Fig. 5, where the percentage of papers that employ at least one of the ten suggested protocols rises with each passing year.

The most common contamination control procedure adopted in the

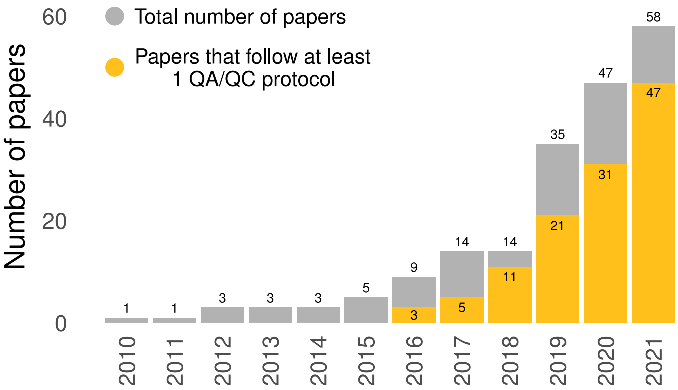

Fig. 5. Proportion of papers that adopted at least one quality assurance and quality control (QA/QC) for preventing sample cross-contamination. The reviewed papers started to employ QA/QC protocols in 2016, with the proportion of papers that use at least one QA/QC protocol increasing with each passing year.

reviewed papers was using clean laboratory equipment and materials, which was reported by 37.8% of the papers (n = 201, considering the papers that employ multiple QA/QC protocols) (Fig. 6). The use of blanks as negative controls (29.4%, n = 201), cotton clothing throughout the analysis (27.9%, n = 201), and glass or metal equipment for sampling and analyzing microplastics (24.9%, n = 201) were also commonly included by the reviewed papers (Fig. 6). Nevertheless, few studies (6%, n = 201) reported cleaning the laboratory equipment between samples, which is an important step to avoid cross-contamination (Fig. 6).

All of the proposed procedures are regarded as intuitive controls that can be easily implemented in most microplastic studies without an elevated associated cost, as the implementation usually requires manageable changes to the laboratory analysis protocols. As an example, while the use of clean laboratory equipment is assumed for any research project, microplastic studies require a 10% acid wash (HCl or HNO_3) for glassware and an ethanol wash for metallic materials in order to remove microplastic residues adsorbed to the equipment or present in the washing water (Brander et al., 2020; Prata et al., 2021). Similarly, microplastic studies require that the equipment is thoroughly cleaned between samples, which is a step that may be absent in the workflow of some laboratories. In consequence, microplastic studies should describe in detail all contamination control procedures adopted throughout the study in a dedicated section of the methodology or in a section of supplementary information in order to increase the reliability of the results.

Microplastic contamination can happen at any point of the study. Even though some contamination sources cannot be avoided (e.g., sampling with plastic equipment like a manta trawl or a plankton mesh), it is possible to address them to ensure high-quality results. Microfibers are regarded as a complicated airborne pollutant, with reports indicating that they are the most abundant indoor airborne contaminant (Brander et al., 2020; Prata et al., 2021). Out of the 193 reviewed papers, 2.1% excluded microfibers from their results due to the high potential of airborne contamination (Chagnon et al., 2018; Ory et al., 2018); however, this omission can generate bias in the reports of a common microplastic shape (Kutralam-Muniasamy et al., 2020a). Most of the protocols outlined by Prata et al. (2021) target airborne microplastic contamination present during the analysis, including the use of blanks, exposed filter papers (or beakers with filtered water), covering the samples when not in use, and working in a controlled-air room (laminar flow hood, fume hood or a restricted air-flow-room). These precautions are required to ensure that any laboratory-based airborne contamination is detected and corrected in the final results (e.g., subtracting the airborne contaminants from the samples).

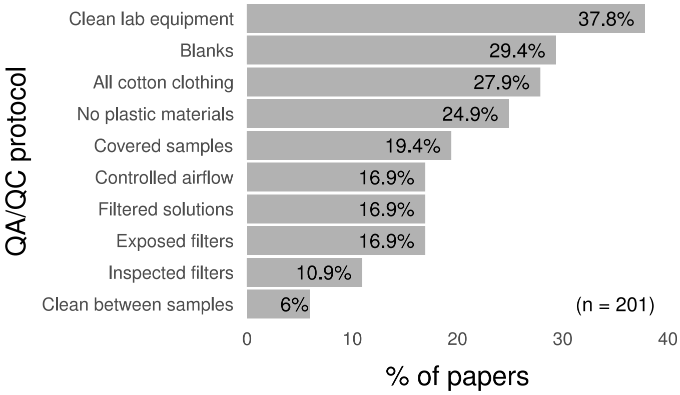

Fig. 6. Percentage of papers that employed the ten quality assurance and quality control (QA/QC) protocols proposed by Prata et al. (2021) to prevent sample cross-contamination. The most frequently employed QA/QC protocol was using clean laboratory equipment following a specific cleaning procedure for microplastic samples (37.8%, n = 201 considering the papers that employed multiple QA/QC protocols).

It should be noted that the protocols summarized in Table S8 should be implemented through every step of the analysis of environmental microplastic samples for future studies: sampling, digestion, density separation, filtration, and characterization (e.g., microscope or spectroscopic technique). Researchers should identify and minimize possible contamination sources that may be present at any step of the analysis workflow, as the contamination control protocols are not as effective if they are not implemented holistically. For example, a study may employ blanks and controlled-air conditions during the digestion, density separation, and filtration steps. However, if no controls are included at the moment of characterizing the samples by optical microscopy, scanning electron microscopy, or spectroscopy techniques (e.g., Raman, FT-IR), the final results are still compromised, even if the researchers followed most QA/QC procedures. Furthermore, the use of appropriate contamination controls should be suited to the objectives and equipment available for each study, as more strict controls are required for characterization techniques with lower detection limits (< 100 μm) in comparison to less sensitive analyses (GESAMP, 2019).

As microplastic research is still in its early stages, the importance of QA/QC protocols has only recently been recognized, with most papers that address the subject being roughly published since 2016 (Brander et al., 2020; European Commission et al., 2013; Masura et al., 2015; Prata et al., 2021). The apparent lack of validated QA/QC protocols in the early 2010s, due to a general absence of information about microplastic contamination in laboratory settings, likely contributed to the relatively high percentage of papers that do not employ QA/QC protocols (Fig. 5). As more information becomes available about microplastic sample contamination (e.g., particle dynamic, possible sources, mitigation strategies), the scientific community is expected to enforce the use of multiple contamination control protocols that ensure high-quality results.

Conclusions and recommendations

The current state of microplastic studies in Latin America and the Caribbean was summarized with a sample of 193 papers that analyzed environmental microplastic concentrations in aquatic and terrestrial ecosystems. The observed research trends include the study of aquatic ecosystems over terrestrial ecosystems, with a notable preference for marine environments and biota samples, particularly fishes, for all of the studied regions (MCAC, SAPC, and SAAC). Additionally, the parameters employed for the characterization of microplastics were highly variable, including shape, color, PCC, and the reported concentration units, which was attributed to factors like the use of redundant categories or the omission of some parameters from the study. However, these factors result from a lack of widely adopted standard protocols in Latin America and the Caribbean, as it has been referred to by multiple authors. Furthermore, the use of QA/QC protocols focused on managing sample cross-contamination has increased overall in recent years, even though the use of multiple contamination controls is still not widely adopted in most papers.

We propose the adoption of standardized sampling, analysis, and reporting guidelines for the Latin American and Caribbean region to address the high variability found among the reviewed papers. Additionally, the use of a common regional protocol would facilitate the migration towards the development of long-term monitoring programs necessary for the creation of environmental risk assessment studies and appropriate legislation. Our review of Open Access standards and reporting guidelines for aquatic microplastics revealed that multiple validated references have been available since 2015, with records of earlier standards existing since 2009, suggesting a widespread lack of recognition of the current standardized protocols in the region.

We suggest the inclusion of GESAMP (2019) in all future studies performing microplastic environmental determinations, as it was considered the most complete standard out of the evaluated references and it can be adapted to a wide range of ecosystems and types of samples. Ideally, the suggested sampling methods and reporting parameters should be followed as described in GESAMP (2019). Furthermore, we propose that the ten QA/QC protocols suggested by Prata et al. (2021) be included whenever possible, as the use of multiple cross-contamination controls provides a higher degree of confidence in the reported results. Nevertheless, regardless of the inclusion of the guidelines outlined by GESAMP (2019) or Prata et al. (2021) to microplastic analysis protocols, researchers should aim to report the parameters considered in this review, which are supplemented with those explained by said standard (e.g., microplastic size reported in multiple size categories, (GESAMP, 2019)).

Overall, the observed trends reflect the research output of a few countries in each region, highlighting Mexico and Colombia for the Central America and Caribbean region (MCAC), Chile for the South American Pacific Coast (SAPC) and Argentina and Brazil for the South American Atlantic Coast (SAAC). These countries have the potential to influence the general direction of the regional microplastic field of study, particularly for small countries with low scientific research output that may be in the early stages of investigating microplastic abundance. Based on the currently available scientific literature, it is likely that novice research groups from small Latin American countries will tend to focus on studying marine ecosystems and biota samples, particularly fishes, as these research topics have the largest established baseline methods for microplastic research in comparison to other environments or types of sample.

Ultimately, the field of microplastic studies in Latin America and the Caribbean suffers from a moderate lack of research output by most countries. However, if established microplastic research groups from influential countries adopt validated standard sampling protocols, reporting guidelines and a comprehensive QA/QC system as an additional resource to their preferred protocols, other countries are most likely to follow their example.

Local, national and regional microplastic monitoring programs based on a standardized methodology are needed in all countries of the Latin America and the Caribbean, although its implementation will be faced with greater challenges in countries that are just starting to investigate microplastic environmental abundance. In consequence, the participation of governments and international cooperation is necessary for achieving large scale monitoring programs, as financing opportunities and cooperation programs at a national and international level would close the gap between Latin American countries with high and low research output, respectively.

CRediT authorship contribution statement

Jose F. Grillo: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Alejandra Guerrero Rebolledo:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Marcos A. Sabino:** Conceptualization, Writing – review & editing, Supervision, Project administration. **Ruth Ramos:** Conceptualization, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors would like to thank Dr. Adriana López-Ordaz for her suggestions to the manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envadv.2022.100236.

References

Ajith, N., Arumugam, S., Parthasarathy, S., Manupoori, S., Janakiraman, S., 2020. Global distribution of microplastics and its impact on marine environment—a review. Environ. Sci. Pollut. Res. 27, 25970–25986. https://doi.org/10.1007/s11356-020-09015-5.

Álvarez-Lopeztello, J., Robles, C., del Castillo, R.F., 2021. Microplastic pollution in neotropical rainforest, savanna, pine plantations, and pasture soils in lowland areas of Oaxaca, Mexico: preliminary results. Ecol. Indic. 121, 107084 https://doi.org/10.1016/j.ecolind.2020.107084.

Alvarez-Zeferino, J.C., Ojeda-Benítez, S., Cruz-Salas, A.A., Martínez-Salvador, C., Vázquez-Morillas, A., 2020. Microplastics in Mexican beaches. Resour. Conserv. Recycl. 155, 104633 https://doi.org/10.1016/j.resconrec.2019.104633.

Araújo, A.P., da, C., Malafaia, G., 2020. Can short exposure to polyethylene microplastics change tadpoles' behavior? A study conducted with neotropical tadpole species belonging to order anura (Physalaemus cuvieri). J. Hazard. Mater. 391, 122214 https://doi.org/10.1016/j.jhazmat.2020.122214.

Ardusso, M., Forero-López, A.D., Buzzi, N.S., Spetter, C.V., Fernández-Severini, M.D., 2021. COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America. Sci. Total Environ. 763, 144365 https://doi.org/10.1016/j.scitotenv.2020.144365.

Baeza, C., Cifuentes, C., González, P., Araneda, A., Barra, R., 2020. Experimental exposure of lumbricus terrestris to microplastics. Water Air Soil Pollut. 231, 308. https://doi.org/10.1007/s11270-020-04673-0.

Ballejo, F., Plaza, P., Speziale, K.L., Lambertucci, A.P., Lambertucci, S.A., 2021. Plastic ingestion and dispersion by vultures may produce plastic islands in natural areas. Sci. Total Environ. 755, 142421 https://doi.org/10.1016/j.scitotenv.2020.142421.

Bandow, N., Will, V., Wachtendorf, V., Simon, F.-G., 2017. Contaminant release from aged microplastic. Environ. Chem. 14, 394. https://doi.org/10.1071/EN17064.

Bermúdez-Guzmán, L., Alpízar-Villalobos, C., Gatgens-García, J., Jiménez-Huezo, G., Rodríguez-Arias, M., Molina, H., Villalobos, J., Paniagua, S.A., Vega-Baudrit, J.R., Rojas-Jimenez, K., 2020. Microplastic ingestion by a herring Opisthonema sp. in the Pacific coast of Costa Rica. Region. Stud. Mar. Sci. 38 https://doi.org/10.1016/j.rsma.2020.101367.

Bivand, R., Rundel, C., 2021. rgeos: Interface to geometry engine - open source ('GEOS').

Borges Ramirez, M.M., Dzul Caamal, R., Rendón von Osten, J., 2019. Occurrence and seasonal distribution of microplastics and phthalates in sediments from the urban channel of the Ria and coast of Campeche, Mexico. Sci. Total Environ. 672, 97–105. https://doi.org/10.1016/j.scitotenv.2019.03.472.

Borges-Ramírez, M.M., Mendoza-Franco, E.F., Escalona-Segura, G., Osten, J.R., 2020. Plastic density as a key factor in the presence of microplastic in the gastrointestinal tract of commercial fishes from Campeche Bay, Mexico. Environ. Pollut. 267, 115659 https://doi.org/10.1016/j.envpol.2020.115659.

Brander, S.M., Renick, V.C., Foley, M.M., Steele, C., Woo, M., Lusher, A., Carr, S., Helm, P., Box, C., Cherniak, S., Andrews, R.C., Rochman, C.M., 2020. Sampling and quality assurance and quality control: a guide for scientists investigating the occurrence of microplastics across matrices. Appl. Spectrosc. 74, 1099–1125. https://doi.org/10.1177/0003702820945713.

Braun, T., Ehrlich, L., Henrich, W., Koeppel, S., Lomako, I., Schwabl, P., Liebmann, B., 2021. Detection of microplastic in human placenta and meconium in a clinical setting. Pharmaceutics 13, 921. https://doi.org/10.3390/pharmaceutics13070921.

Brennecke, D., Ferreira, E.C., Costa, T.M.M., Appel, D., da Gama, B.A.P., Lenz, M., 2015. Ingested microplastics (>100μm) are translocated to organs of the tropical fiddler crab Uca rapax. Mar. Pollut. Bull. 96, 491–495. https://doi.org/10.1016/j.marpolbul.2015.05.001.

Brentano, R., Petry, M.V., 2020. Marine debris ingestion and human impacts on the Pygmy sperm whale (Kogia breviceps) in southern Brazil. Mar. Pollut. Bull. 150, 110595 https://doi.org/10.1016/j.marpolbul.2019.110595.

Cabrera, M., Valencia, B.G., Lucas-Solis, O., Calero, J.L., Maisincho, L., Conicelli, B., Massaine Moulatlet, G., Capparelli, M.V., 2020. A new method for microplastic sampling and isolation in mountain glaciers: a case study of one antisana glacier, Ecuadorian Andes. Case Stud. Chem. Environ. Eng. 2, 100051 https://doi.org/10.1016/j.cscee.2020.100051.

Calderon, E.A., Hansen, P., Rodríguez, A., Blettler, M.C.M., Syberg, K., Khan, F.R., 2019. Microplastics in the digestive tracts of four fish species from the Ciénaga Grande de Santa Marta Estuary in Colombia. Water Air Soil Pollut. 230, 257. https://doi.org/10.1007/s11270-019-4313-8.

Carrasco, A., Pulgar, J., Quintanilla-Ahumada, D., Perez-Venegas, D., Quijón, P.A., Duarte, C., 2019. The influence of microplastics pollution on the feeding behavior of a prominent sandy beach amphipod, Orchestoidea tuberculata (Nicolet, 1849). Mar. Pollut. Bull. 145, 23–27. https://doi.org/10.1016/j.marpolbul.2019.05.018.

Castro, R.O., Silva, M.L.da, Marques, M.R.C., Araújo, F.V.de, 2020. Spatio-temporal evaluation of macro, meso and microplastics in surface waters, bottom and beach sediments of two embayments in Niterói, RJ, Brazil. Mar. Pollut. Bull. 160, 111537 https://doi.org/10.1016/j.marpolbul.2020.111537.

Chagnon, C., Thiel, M., Antunes, J., Ferreira, J.L., Sobral, P., Ory, N.C., 2018. Plastic ingestion and trophic transfer between Easter Island flying fish (Cheilopogon rapanouiensis) and yellowfin tuna (Thunnus albacares) from Rapa Nui (Easter Island). Environ. Pollut. 243, 127–133. https://doi.org/10.1016/j.envpol.2018.08.042.

Chen, Q., Li, Y., Li, B., 2020. Is color a matter of concern during microplastic exposure to Scenedesmus obliquus and Daphnia magna? J. Hazard. Mater. 383, 121224 https://doi.org/10.1016/j.jhazmat.2019.121224.

Connors, E.J., 2017. Distribution and biological implications of plastic pollution on the fringing reef of Mo'orea, French Polynesia. PeerJ 5, e3733. https://doi.org/10.7717/peerj.3733.

Corradini, F., Casado, F., Leiva, V., Huerta-Lwanga, E., Geissen, V., 2021. Microplastics occurrence and frequency in soils under different land uses on a regional scale. Sci. Total Environ. 752, 141917 https://doi.org/10.1016/j.scitotenv.2020.141917.

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E., Geissen, V., 2019. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Sci. Total Environ. 671, 411–420. https://doi.org/10.1016/j.scitotenv.2019.03.368.

Costa, L.L., Arueira, V.F., da Costa, M.F., Di Beneditto, A.P.M., Zalmon, I.R., 2019. Can the Atlantic ghost crab be a potential biomonitor of microplastic pollution of sandy beaches sediment? Mar. Pollut. Bull. 145, 5–13. https://doi.org/10.1016/j.marpolbul.2019.05.019.

da Costa Araújo, A.P., de Andrade Vieira, J.E., Malafaia, G., 2020. Toxicity and trophic transfer of polyethylene microplastics from Poecilia reticulata to Danio rerio. Sci. Total Environ. 742, 140217 https://doi.org/10.1016/j.scitotenv.2020.140217.

da Costa Araújo, A.P., Malafaia, G., 2021. Microplastic ingestion induces behavioral disorders in mice: a preliminary study on the trophic transfer effects via tadpoles and fish. J. Hazard. Mater. 401, 123263 https://doi.org/10.1016/j.jhazmat.2020.123263.

de Carvalho, R.H., Lacerda, P.D., da Silva Mendes, S., Barbosa, B.C., Paschoalini, M., Prezoto, F., de Sousa, B.M., 2015. Marine debris ingestion by sea turtles (Testudines) on the Brazilian coast: an underestimated threat? Mar. Pollut. Bull. 101, 746–749. https://doi.org/10.1016/j.marpolbul.2015.10.002.

de Ruijter, V.N., Redondo-Hasselerharm, P.E., Gouin, T., Koelmans, A.A., 2020. Quality criteria for microplastic effect studies in the context of risk assessment: a critical review. Environ. Sci. Technol. 54, 11692–11705. https://doi.org/10.1021/acs.est.0c03057.

De-la-Torre, G., Mendoza-Castilla, L., Pilar, R., 2019. Microplastic contamination in market bivalve Argopecten purpuratus from Lima, Peru. manglar 16, 85–89. https://doi.org/10.17268/manglar.2019.012.

Denuncio, P., Bastida, R., Dassis, M., Giardino, G., Gerpe, M., Rodríguez, D., 2011. Plastic ingestion in Franciscana dolphins, Pontoporia blainvillei (Gervais and d'Orbigny, 1844), from Argentina. Mar. Pollut. Bull. 62, 1836–1841. https://doi.org/10.1016/j.marpolbul.2011.05.003.

Détrée, C., Gallardo-Escárate, C., 2017. Polyethylene microbeads induce transcriptional responses with tissue-dependent patterns in the mussel Mytilus galloprovincialis. J. Molluscan Stud. 83, 220–225. https://doi.org/10.1093/mollus/eyx005.

European Commission, Joint Research Centre, 2013. Institute for Environment and Sustainability, MSFD Technical Subgroup on Marine Litter. Guidance on monitoring of marine litter in European seas. Publications Office, Luxembourg.

FAO, 2022a. Fishery and aquaculture country profiles. Peru [WWW Document]. URL https://www.fao.org/fishery/en/facp/per?lang=es (accessed 1.15.22).

FAO, 2022b. Fishery and aquaculture country profiles. Chile [WWW Document]. URL https://www.fao.org/fishery/en/facp/chl?lang=es (accessed 1.15.22).

Froese, R., Pauly, D., 2021. FishBase [WWW Document]. URL www.fishbase.org (accessed 1.15.22).

GESAMP, 2019. Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (No. 99), GESAMP Reports & Studies Series. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, United Nations Office Nairobi.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, e1700782 https://doi.org/10.1126/sciadv.1700782.

Gimiliani, G.T., Fornari, M., Redígolo, M.M., Willian Vega Bustillos, J.O., Moledo de Souza Abessa, D., Faustino Pires, M.A., 2020. Simple and cost-effective method for microplastic quantification in estuarine sediment: a case study of the Santos and São Vicente Estuarine System. Case Stud. Chem. Environ. Eng. 2, 100020 https://doi.org/10.1016/j.cscee.2020.100020.

González Carman, V., Acha, E.M., Maxwell, S.M., Albareda, D., Campagna, C., Mianzan, H., 2014. Young green turtles, Chelonia mydas, exposed to plastic in a frontal area of the SW Atlantic. Mar. Pollut. Bull. 78, 56–62. https://doi.org/10.1016/j.marpolbul.2013.11.012.

González, D., Hanke, G., Tweehuysen, G., Bellert, B., Holzhauer, M., Palatinus, A., Hohenblum, P., Oosterbaan, L., 2016. Riverine Litter Monitoring: Options and Recommendations : MSFD GES TG Marine Litter Thematic Report. MSFD GES TG Marine Litter Thematic Report. Publications Office.

Gorman, D., Gutiérrez, A.R., Turra, A., Manzano, A.B., Balthazar-Silva, D., Oliveira, N.R., Harari, J., 2020. Predicting the dispersal and accumulation of microplastic pellets within the estuarine and coastal waters of South-Eastern Brazil using integrated rainfall data and Lagrangian particle tracking models. Front. Environ. Sci. 8, 559405 https://doi.org/10.3389/fenvs.2020.559405.

Gorman, D., Moreira, F.T., Turra, A., Fontenelle, F.R., Combi, T., Bícego, M.C., de Castro Martins, C., 2019. Organic contamination of beached plastic pellets in the South Atlantic: risk assessments can benefit by considering spatial gradients. Chemosphere 223, 608–615. https://doi.org/10.1016/j.chemosphere.2019.02.094.

Grillo, J.F., Sabino, M.A., Ramos, R., 2021. Short-term ingestion and tissue incorporation of Polystyrene microplastic in the scleractinian coral Porites porites. Region. Stud. Mar. Sci. 43, 101697 https://doi.org/10.1016/j.rsma.2021.101697.

Iannacone, J., Principe, F., Minaya, D., Panduro, G., Carhuapoma, M., Alvariño, L., 2021. Microplásticos en peces marinos de importancia económica en Lima, Perú. Rev. Investig. Vet. Perú 32, e20038. https://doi.org/10.15381/rivep.v32i2.20038.

Ibrahim, Y.S., Tuan Anuar, S., Azmi, A.A., Wan Mohd Khalik, W.M.A., Lehata, S., Hamzah, S.R., Ismail, D., Ma, Z.F., Dzulkarnaen, A., Zakaria, Z., Mustaffa, N., Tuan Sharif, S.E., Lee, Y.Y., 2021. Detection of microplastics in human colectomy specimens. JGH Open 5, 116–121. https://doi.org/10.1002/jgh3.12457.

Jenner, L.C., Rotchell, J.M., Bennett, R.T., Cowen, M., Tentzeris, V., Sadofsky, L.R., 2022. Detection of microplastics in human lung tissue using μFTIR spectroscopy. Sci. Total Environ. 154907 https://doi.org/10.1016/j.scitotenv.2022.154907.

Kutralam-Muniasamy, G., Pérez-Guevara, F., Elizalde-Martínez, I., Shruti, V.C., 2020a. Review of current trends, advances and analytical challenges for microplastics contamination in Latin America. Environ. Pollut. 267, 115463 https://doi.org/10.1016/j.envpol.2020.115463.

Kutralam-Muniasamy, G., Pérez-Guevara, F., Elizalde-Martínez, I., Shruti, V.C., 2020b. Branded milks – are they immune from microplastics contamination? Sci. Total Environ. 714, 136823 https://doi.org/10.1016/j.scitotenv.2020.136823.

Leslie, H.A., van Velzen, M.J.M., Brandsma, S.H., Vethaak, A.D., Garcia-Vallejo, J.J., Lamoree, M.H., 2022. Discovery and quantification of plastic particle pollution in human blood. Environ. Int. 107199 https://doi.org/10.1016/j.envint.2022.107199.

Li, P., Wang, X., Su, M., Zou, X., Duan, L., Zhang, H., 2021. Characteristics of plastic pollution in the environment: a review. Bull. Environ. Contam. Toxicol. 107, 577–584. https://doi.org/10.1007/s00128-020-02820-1.

Liu, H., Liu, K., Fu, H., Ji, R., Qu, X., 2020. Sunlight mediated cadmium release from colored microplastics containing cadmium pigment in aqueous phase. Environ. Pollut. 263, 114484 https://doi.org/10.1016/j.envpol.2020.114484.

Luo, X., Wang, Z., Yang, L., Gao, T., Zhang, Y., 2022. A review of analytical methods and models used in atmospheric microplastic research. Sci. Total Environ. 828, 154487 https://doi.org/10.1016/j.scitotenv.2022.154487.

Martínez Silva, P., Nanny, M.A., 2020. Impact of microplastic fibers from the degradation of nonwoven synthetic textiles to the Magdalena River water column and river sediments by the City of Neiva, Huila (Colombia). Water 12, 1210. https://doi.org/10.3390/w12041210.

Mason, S.A., Welch, V.G., Neratko, J., 2018. Synthetic polymer contamination in bottled water. Front. Chem. 6, 407. https://doi.org/10.3389/fchem.2018.00407.

Masura, J., Baker, J., Foster, G., Arthur, C., 2015. Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments (Technical Memorandum No. NOS-OR&R-48). NOAA, United States.

Montecinos, S., Tognana, S., Pereyra, M., Silva, L., Tomba, J.P., 2021. Study of a stream in Argentina with a high concentration of microplastics: preliminary analysis of the methodology. Sci. Total Environ. 760, 143390 https://doi.org/10.1016/j.scitotenv.2020.143390.

Narciso-Ortiz, L., Coreño-Alonso, A., Mendoza-Olivares, D., Lucho-Constantino, C.A., Lizardi-Jiménez, M.A., 2020. Baseline for plastic and hydrocarbon pollution of rivers, reefs, and sediment on beaches in Veracruz State, México, and a proposal for bioremediation. Environ. Sci. Pollut. Res. 27, 23035–23047. https://doi.org/10.1007/s11356-020-08831-z.

Nunes, L.S., Silva, A.G., Espínola, L.A., Blettler, M.C.M., Simões, N.R., 2021. Intake of microplastics by commercial fish: a Bayesian approach. Environ. Monit. Assess. 193, 402. https://doi.org/10.1007/s10661-021-09156-1.

Opitz, T., Benítez, S., Fernández, C., Osores, S., Navarro, J.M., Rodríguez-Romero, A., Lohrmann, K.B., Lardies, M.A., 2021. Minimal impact at current environmental concentrations of microplastics on energy balance and physiological rates of the giant mussel Choromytilus chorus. Mar. Pollut. Bull. 162, 111834 https://doi.org/10.1016/j.marpolbul.2020.111834.

Ormaza-Gonzaìlez, F.I., Castro-Rodas, D., Statham, P.J., 2021. COVID-19 impacts on beaches and coastal water pollution at selected sites in ecuador, and management proposals post-pandemic. Front. Mar. Sci. 8, 669374 https://doi.org/10.3389/fmars.2021.669374.

Ory, N., Chagnon, C., Felix, F., Fernández, C., Ferreira, J.L., Gallardo, C., Garcés Ordóñez, O., Henostroza, A., Laaz, E., Mizraji, R., Mojica, H., Murillo Haro, V., Ossa Medina, L., Preciado, M., Sobral, P., Urbina, M.A., Thiel, M., 2018. Low prevalence of microplastic contamination in planktivorous fish species from the southeast Pacific Ocean. Mar. Pollut. Bull. 127, 211–216. https://doi.org/10.1016/j.marpolbul.2017.12.016.

Pazos, R.S., Suárez, J.C., Gómez, N., 2020. Study of the plastisphere: biofilm development and presence of faecal indicator bacteria on microplastics from the Río de la Plata estuary. ECOS 29. https://doi.org/10.7818/ECOS.2069.

Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data. R J. 10, 439. https://doi.org/10.32614/RJ-2018-009.

Pedersen, T.L., 2020. patchwork: The composer of plots.

Pelamatti, T., Fonseca-Ponce, I.A., Rios-Mendoza, L.M., Stewart, J.D., Marín-Enríquez, E., Marmolejo-Rodriguez, A.J., Hoyos-Padilla, E.M., Galván-Magaña, F., González-Armas, R., 2019. Seasonal variation in the abundance of marine plastic debris in Banderas Bay, Mexico. Mar. Pollut. Bull. 145, 604–610. https://doi.org/10.1016/j.marpolbul.2019.06.062.

Pozo, K., Gomez, V., Torres, M., Vera, L., Nuñez, D., Oyarzún, P., Mendoza, G., Clarke, B., Fossi, M.C., Baini, M., Přibylová, P., Klánová, J., 2019. Presence and characterization of microplastics in fish of commercial importance from the Biobío region in central

Chile. Mar. Pollut. Bull. 140, 315–319. https://doi.org/10.1016/j.marpolbul.2019.01.025.

Prata, J.C., Reis, V., da Costa, J.P., Mouneyrac, C., Duarte, A.C., Rocha-Santos, T., 2021. Contamination issues as a challenge in quality control and quality assurance in microplastics analytics. J. Hazard. Mater. 403, 123660 https://doi.org/10.1016/j.jhazmat.2020.123660.

Quesadas-Rojas, M., Enriquez, C., Valle-Levinson, A., 2021. Natural and anthropogenic effects on microplastic distribution in a hypersaline lagoon. Sci. Total Environ. 776, 145803 https://doi.org/10.1016/j.scitotenv.2021.145803.

Core Team, R, 2021. A language and environment for statistical computing. Vienna, Austria.

Ramos, L., Berenstein, G., Hughes, E.A., Zalts, A., Montserrat, J.M., 2015. Polyethylene film incorporation into the horticultural soil of small periurban production units in Argentina. Sci. Total Environ. 523, 74–81. https://doi.org/10.1016/j.scitotenv.2015.03.142.

Rangel-Buitrago, N., Williams, A., Anfuso, G., 2018. Killing the goose with the golden eggs: litter effects on scenic quality of the Caribbean coast of Colombia. Mar. Pollut. Bull. 127, 22–38. https://doi.org/10.1016/j.marpolbul.2017.11.023.

Ríos, M.F., Hernández-Moresino, R.D., Galván, D.E., 2020. Assessing urban microplastic pollution in a benthic habitat of Patagonia Argentina. Mar. Pollut. Bull. 159, 111491 https://doi.org/10.1016/j.marpolbul.2020.111491.

Rodríguez Chialanza, M., Sierra, I., Pérez Parada, A., Fornaro, L., 2018. Identification and quantitation of semi-crystalline microplastics using image analysis and differential scanning calorimetry. Environ. Sci. Pollut. Res. 25, 16767–16775. https://doi.org/10.1007/s11356-018-1846-0.

Ryan, M.G., Watkins, L., Walter, M.T., 2019. Hudson River juvenile Blueback herring avoid ingesting microplastics. Mar. Pollut. Bull. 146, 935–939. https://doi.org/10.1016/j.marpolbul.2019.07.004.

Salazar-Pérez, C., Amezcua, F., Rosales-Valencia, A., Green, L., Pollorena-Melendrez, J. E., Sarmiento-Martínez, M.A., Tomita Ramírez, I., Gil-Manrique, B.D., Hernandez-Lozano, M.Y., Muro-Torres, V.M., Green-Ruiz, C., Piñon-Colin, T.D.J., Wakida, F.T., Barletta, M., 2021. First insight into plastics ingestion by fish in the Gulf of California, Mexico. Mar. Pollut. Bull. 171, 112705 https://doi.org/10.1016/j.marpolbul.2021.112705.

Sánchez-Hernández, L.J., Ramírez-Romero, P., Rodríguez-González, F., Ramos-Sánchez, V.H., Márquez Montes, R.A., Romero-Paredes Rubio, H., Sujitha, S.B., Jonathan, M.P., 2021. Seasonal evidences of microplastics in environmental matrices of a tourist dominated urban estuary in Gulf of Mexico, Mexico. Chemosphere 277, 130261. https://doi.org/10.1016/j.chemosphere.2021.130261.

Sierra, I., Chialanza, M.R., Faccio, R., Carrizo, D., Fornaro, L., Pérez-Parada, A., 2020. Identification of microplastics in wastewater samples by means of polarized light optical microscopy. Environ. Sci. Pollut. Res. 27, 7409–7419. https://doi.org/10.1007/s11356-019-07011-y.

Silva, M.M., Maldonado, G.C., Castro, R.O., de Sá Felizardo, J., Cardoso, R.P., Anjos, R.M. dos, Araújo, F.V.de, 2019. Dispersal of potentially pathogenic bacteria by plastic debris in Guanabara Bay, RJ, Brazil. Mar. Pollut. Bull. 141, 561–568. https://doi.org/10.1016/j.marpolbul.2019.02.064.

South, A., 2017a. rnaturalearth: World Map Data from Natural Earth.

South, A., 2017b. rnaturalearthdata: World vector map data from natural earth used in "rnaturalearth.".

Thiel, M., de Veer, D., Espinoza-Fuenzalida, N.L., Espinoza, C., Gallardo, C., Hinojosa, I. A., Kiessling, T., Rojas, J., Sanchez, A., Sotomayor, F., Vasquez, N., Villablanca, R., 2021. COVID lessons from the global south – face masks invading tourist beaches and recommendations for the outdoor seasons. Sci. Total Environ. 786, 147486 https://doi.org/10.1016/j.scitotenv.2021.147486.

Truchet, D.M., López, A.D.F., Ardusso, M.G., Rimondino, G.N., Buzzi, N.S., Malanca, F.E., Spetter, C.V., Severini, M.D.F., 2021. Microplastics in bivalves, water and sediments from a touristic sandy beach of Argentina. Mar. Pollut. Bull. 173, 113023 https://doi.org/10.1016/j.marpolbul.2021.113023.

Turner, A., Filella, M., 2021. Hazardous metal additives in plastics and their environmental impacts. Environ. Int. 156, 106622 https://doi.org/10.1016/j.envint.2021.106622.

UNESCO Institute for Statistics, 2022. UNESCO Institute for Statistics (UIS): Science, Technology and Innovation [WWW Document]. URL http://data.uis.unesco.org/Index.aspx?DataSetCode=SCN_DS&lang=en# (accessed 4.8.22).

United Nations, 2018. The 2030 Agenda and the Sustainable Development Goals an opportunity for Latin America and the Caribbean (No. LC/G.2681-P/Rev.3). Santiago.

United Nations Conference on Trade and Development, 2021. From recovery to resilience: the development dimension, Trade and development report. Geneva.

United Nations Environment Programme, 2021. Policies, regulations and strategies in Latin America and the Caribbean to prevent marine litter and plastic waste: information report to the XXII LAC forum of ministers of environment UNEP – Latin America and the Caribbean office.

United Nations Environment Programme, 2020. Monitoring plastics in rivers and lakes: guidelines for the harmonization of methodologies (No. DEW/2317/NA). United Nations Environment Programme, Nairobi.

Wagner, G., 1995. Basic approaches and methods for quality assurance and quality control in sample collection and storage for environmental monitoring. Sci. Total Environ. 176, 63–71 https://doi.org/10.1016/0048-9697(95)04830-8.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to the tidyverse. JOSS 4, 1686. https://doi.org/10.21105/joss.01686.

Wilke, C.O., 2020. ggtext: Improved text rendering support for "ggplot2.".

Williams, A.T., Rangel-Buitrago, N.G., Anfuso, G., Cervantes, O., Botero, C.M., 2016. Litter impacts on scenery and tourism on the Colombian north Caribbean coast. Tour. Manage. 55, 209–224. https://doi.org/10.1016/j.tourman.2016.02.008.

WoRMS Editorial Board, 2022. World Register of Marine Species. https://doi.org/10.14284/170.

Xiong, X., Tu, Y., Chen, X., Jiang, X., Shi, H., Wu, C., Elser, J.J., 2019. Ingestion and egestion of polyethylene microplastics by goldfish (Carassius auratus): influence of color and morphological features. Heliyon 5, e03063. https://doi.org/10.1016/j.heliyon.2019.e03063.

Yorio, P., Marinao, C., Suárez, N., 2014. Kelp Gulls (Larus dominicanus) killed and injured by discarded monofilament lines at a marine recreational fishery in northern Patagonia. Mar. Pollut. Bull. 85, 186–189. https://doi.org/10.1016/j.marpolbul.2014.05.052.

Zhang, Y., Gao, T., Kang, S., Shi, H., Mai, L., Allen, D., Allen, S., 2022. Current status and future perspectives of microplastic pollution in typical cryospheric regions. Earth Sci. Rev. 226, 103924 https://doi.org/10.1016/j.earscirev.2022.103924.

Ziajahromi, S., Leusch, F.D.L., 2022. Systematic assessment of data quality and quality assurance/quality control (QA/QC) of current research on microplastics in biosolids and agricultural soils. Environ. Pollut. 294, 118629 https://doi.org/10.1016/j.envpol.2021.118629.