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Microplastics in Brazilian coastal environments: a systematic review

Microplásticos nos ambientes costeiros brasileiros: uma revisão sistemática

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ABSTRACT

This systematic review aimed to evaluate the current scenario of research on microplastics (MPs) in Brazilian coastal environments, considering beaches and also environments not yet reported in previous reviews, such as estuaries, mangroves, and reefs. Five databases were consulted, and 102 articles on the subject published between 2018 and 2023 were selected. The universities and research institutions that most published in this period were from the Southeast region (37.3% of the articles), followed by the Northeast region (34.3%). Universities in the states of Rio de Janeiro (15.7%) and Pernambuco (15.7%) lead the number of publications, followed by São Paulo (11.8%), Rio Grande do Sul (11.8%), and Espírito Santo (7.8%). About the coastal environments studied, 70% of the studies evaluated the presence of MPs on beaches, 26% on mangroves, 2% on estuaries, and 2% on coral reefs. Studies that evaluated its presence in marine biota corresponded to 43% of the articles, sediment (42%), and water (14%). The most studied organisms were bony fish (42%), bivalves (17%), crustaceans (7%), seabirds (7%), turtles (7%), and microfauna (5%). Despite growing, the distribution of study locations is still uneven and not related to the length of the coastline of each state. As for the origin, the works compiled in this study infer that the main sources of PMs are tourism, fishing, and river discharge, while the action of waves and winds contributes to the dispersion of these particles to less urbanized beaches and remote locations.

Keywords: microplastics; coastal ecosystems; beaches; mangrove; estuaries; environmental monitoring.

RESUMO

Esta revisão sistemática teve por objetivo avaliar o cenário atual da pesquisa com microplásticos (MP) em ambientes costeiros brasileiros, considerando praias e também ambientes ainda não relatados em revisões anteriores, como estuários, manguezais e recifes. Cinco bases de dados foram consultadas, e foram selecionados 102 artigos sobre o tema, publicados entre 2018 e 2023. As instituições de ensino e pesquisa que mais publicaram nesse período foram da Região Sudeste (37,3% dos artigos), seguida da Região Nordeste (34,3%). Universidades dos estados do Rio de Janeiro (15,7%) e Pernambuco (15,7%) lideram o número de publicações, seguidas pelas de São Paulo (11,8%), Rio Grande do Sul (11,8%) e Espírito Santo (7,8%). Acerca dos ambientes costeiros estudados, 70% dos estudos avaliaram a presença de MP em praias, 26% em manguezais, 2% em estuários e 2% em recifes de corais. Estudos que avaliaram a sua presença na biota marinha corresponderam a 43% dos artigos, sedimento (42%) e água (14%). Os organismos mais estudados foram os peixes ósseos (42%), bivalves (17%), crustáceos (7%), aves marinhas (7%), tartarugas (7%) e microfauna (5%). Apesar de crescente, a distribuição das localidades dos estudos ainda é desigual e não relacionada à extensão de faixa litorânea de cada estado. Quanto à origem, os trabalhos compilados no presente estudo permitem inferir que as principais fontes de MP são o turismo, a pesca e a descarga de rios, enquanto a ação das ondas e ventos contribui para a dispersão dessas partículas para praias menos urbanizadas e localidades remotas.

Palavras-chave: microplásticos; ecossistemas costeiros; praias; manguezais; estuários; monitoramento ambiental.

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Introduction

Brazil is the fourth producer of plastic waste in the world, generating 11.3 million tons per year (Fundação Heinrich Böll, 2020). Of this total, only 1.28% is recycled; the remainder is incinerated, buried in landfills, or reaches the land and sea (Drabinski et al., 2023). The presence of plastic waste in marine and coastal environments has grown significantly, both due to excessive consumption of these materials and the lack of adequate management of this waste (Castro et al., 2018). Plastic waste present in the environment is classified by its size into macroplastics (>20 mm), mesoplastics (5–20 mm), and microplastics (MPs), which correspond to particles with sizes smaller than 5 mm (Barnes et al., 2009).

MPs can be classified as primary or secondary, with primary materials being those originally produced in small dimensions to meet their industrial purpose (e.g., exfoliating agents in cosmetics, abrasives in cleaning products, etc.). Secondary MPs are derived from the environmental decomposition of macroplastics as a result of weathering (mechanical wear, solar radiation, thermal reactions, and biodegradation, among others) and constitute the majority of MPs in the oceans (Andrady, 2011; Xu et al., 2020). Due to their high persistence and mobility, MPs have become ubiquitous on a global scale, being detected in various environmental compartments, such as beaches (Alvarez-Zeferino et al., 2020; Akkajit et al., 2021), mangroves (Deng et al., 2020; Celis-Hernández et al., 2021), estuaries (Harris, 2020; Pagter et al., 2020; Villagran et al., 2020), continental shelf (Carretero et al., 2021), surface waters (Silvestrova and Stepanova, 2021), water column (Defontaine et al., 2021), sediments (Cruz et al., 2019; Pagter et al., 2020), and even in the deep ocean (Zhang et al., 2020).

In the aquatic environment, MPs affect the balance of ecosystems, as they result in direct and indirect effects on the health of organisms at different trophic levels. Due to their reduced dimensions, they become available to marine biota and can be ingested by both planktonic organisms and large animals, such as fish and whales (Cole et al., 2013; Lusher et al., 2015; Ferreira et al., 2016; Auta et al., 2017). False satiety, blockage of enzyme production, reproductive complications, reduced growth rate, and oxidative stress are some of the possible effects reported by organisms ingesting MP particles (Fossi et al., 2016; Sutton et al., 2016). MPs can serve as a substrate for the transport of pathogenic microorganisms (Harrison et al., 2014), in addition to adsorbing toxic substances present in water, generating bioaccumulation and biomagnification in the trophic chain (Reisser et al., 2014).

Recent work has been carried out to evaluate the scenario of research with macro and MPs in Brazilian ecosystems. Castro et al. (2018) carried out a literature review on pollution by MPs in Brazilian aquatic ecosystems, both marine and freshwater, analyzing this pollutant in samples of sandy sediments, plankton, and other invertebrates and vertebrates. All articles on MPs in Brazil available until October 2017 were used in this review, resulting in a total of 35 publications. Videla and Araújo (2021) evaluated 81 publications between 2008 and 2019 with the aim of discussing the presence of plastic macrodebris (macroplastics), their possible sources, forms of distribution, and consequences for the different coastal ecosystems in Brazil. To track how research on MPs in environmental samples in Latin America has been conducted, Fernandes et al. (2022) carried out a systematic review of the literature, considering articles published between 1990 and 2021. The main objectives of this study were to list out the methods of sampling, extraction, and characterization in different environmental compartments, provide a better understanding of MP contamination in Latin American countries, and collect information on the impacts and toxicological effects caused by MPs. A total of 196 articles were considered for this review. Finally, Oliveira et al. (2023) published a recent review presenting studies of MP contamination in sediment, water, and biota, specifically on Brazilian sandy beaches (2009–2021). The bibliographic search was carried out in the Scopus, Google Scholar, SciELO, and Web of Science databases, and 34 articles were selected for the review.

Given the global scenario that demonstrates the relevance and emergence of studies on environmental monitoring of plastic materials and their resulting effects in aquatic environments, it is opportune to understand the panorama of knowledge already consolidated by groups of Brazilian researchers, especially with regard to the presence of MPs in national coastal environments. Therefore, the objective of this systematic review was to evaluate the current scenario of research on MPs in Brazilian coastal environments, considering beaches and also environments not yet reported in previous reviews, such as estuaries, mangroves, and reefs. The aim is to: i. identify the main Brazilian teaching and research institutions responsible for MPs monitoring studies in recent years; ii. verify the distribution of studies in relation to the types of coastal environments, the environmental matrices analyzed, and the organisms sampled; and iii. raise the main results of MPs monitoring studies in coastal environments, depending on concentrations/densities, main morphotypes, colors, and types of polymers. As a reference source, peer-reviewed articles published between 2018 and 2023 were used.

Methodology

A systematic literature review was carried out according to the PRISMA protocol (Moher et al., 2015). The following databases were used: Scopus, SciELO, Science Direct, Web of Science, and Embase. The search for articles was carried out until January 24, 2023 and used the following combinations of keywords and/or descriptive terms with the Boolean operators "AND" and "OR" (Table 1).

During the search in the databases, a preliminary analysis of the title, abstract, and keywords was carried out, and, in addition, only articles (research and review) published in peer-reviewed journals between 2018 and 2023 were considered. The bibliographic search resulted in a total of 13,721 articles (Scopus=1,870; SciELO=404; Science Direct=7,661; Web of Science=2,683; and Embase=1,103). The identification and exclusion of repeated articles were carried out using the reference manager Mendeley® (Elsevier, *online* version), resulting in a set of 989 articles.

The preliminary content analysis and selection of references by adherence were carried out manually, by reading the titles, abstracts, and keywords of these articles. The objective was to select research works that presented monitoring and characterization of plastic materials (including, but not limited to, MPs) in Brazilian coastal environments such as beaches, bays, oceanic islands, coral reefs, mangroves, and estuaries. Review articles aligned with the purpose of the study were also selected. Articles dealing with the following were excluded: a. studies not conducted in Brazil; b. studies carried out in a freshwater environment (rivers and lakes) that is not part of an estuarine environment; c. works that exclusively performed bioassays with MPs in freshwater and/marine organisms; and d. work focused on adsorption, oxidation, and biodegradation. After the screening stage, a total of 102 articles were selected to compose the present systematic review (Figure 1).

Table 1 – Combinations of keywords and/or terms used to search for references in the selected databases from 2018 to 2023.

KEYWORDS AND TERMS
“microplastics” AND “Brazil”
“microplastics” AND “Brazil” AND “coast”
“microplastics” AND “Brazil “ AND “beaches”
“microplastics” AND “brazilians beaches” OR “brazilian coast”
“microplastics pollution” AND “Brazil” AND “coast”
“microplastics pollution” AND “Brazil “ AND “beaches”
“microplastics pollution” AND “brazilians beaches” OR “brazilian coast”
“microplastics characterization” AND “Brazil” AND “coast”
“microplastics characterization” AND “brazilians beaches” OR “brazilian coast”
“microplastics characterization” AND “Brazil “ AND “beaches”

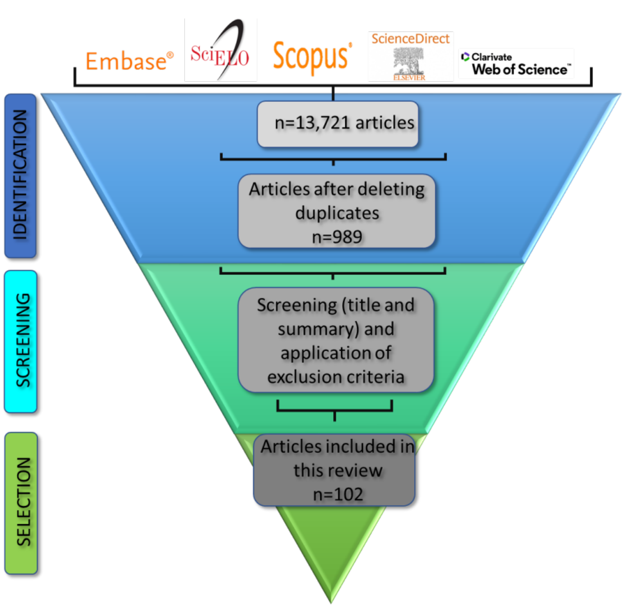


Figure 1 – Systematic literature review procedure on microplastics in Brazilian coastal environments.

Results and discussion

Overview of research with microplastics in Brazilian coastal environments: bibliometric analysis

The first Brazilian publication on the topic occurred in 2009, and after that, the number of publications has increased; however, the geographic distribution of study sites has been quite asymmetrical (Castro et al., 2018). Understanding phenomena related to the presence of MPs in environmental compartments and aspects such as interaction with biota, impacts on human health, the influence of anthropogenic activities, and climatic phenomena on the occurrence, distribution, and accumulation of these residues requires the development of comprehensive studies and the availability of data in the most diverse ecosystems.

Considering the total number of articles selected in this work, 90 refer to monitoring studies in various Brazilian coastal environments and 11 are literature reviews (Figure 2 and Supplementary Table S2). A substantial increase in publications was observed between 2018 (11) and 2020 (31), maintaining the number in the following years, probably due to the impossibility of carrying out monitoring studies during the COVID-19 pandemic period. During the same period, there was a significant increase in international collaboration in publications, which demonstrates greater interest from international researchers in relation to the topic of MPs in Brazilian environments. In 2018, just only one of the publications was the result of collaboration with foreign research groups, while in 2022, there were seven works (21.9%) carried out with international participation.

Considering the 30 publications with international partnerships, we can emphasize the participation of universities and/or research institutes from France (17%), USA (11%), Italy (11%), UK (11%), and Australia (11%). Among Latin American countries, Argentina and Uruguay stood out, with 8% and 6% of publications, respectively (Figure 3).

Regarding journals, the majority of articles analyzed in this review were published in Marine Pollution Bulletin (48%, impact factor: 5.8), followed by Science of The Total Environment – STOTEN (11%, impact factor: 9. 8), Environmental Pollution (9%, impact factor: 8.9), and Regional Studies in Marine Science (4%, impact factor: 2.1) (Table 2).

The quality of the work and the relevance of the topic in the context of Brazilian environments are evident in the 24 publications in journals with a high impact factor (IF>8.0), such as STOTEN and Environmental Pollution. During 2018, no articles on the topic of this review were published in STOTEN; from 2021 onward, three articles were observed each year.

Regarding the origin of the educational and research institutions that were most published between 2018 and 2023, the Southeast region stands out with 37.3% of the articles, followed by the Northeast region (34.3%), South (20.6%), North (7%), and Midwest (1%) (Figure 4). In the Southeast region, most articles were published by Rio de Janeiro institutions (15.7%), followed by São Paulo (11.8%), Espírito Santo (7.8%), and Minas Gerais (2%). The Pernambuco state leads in the Northeast region

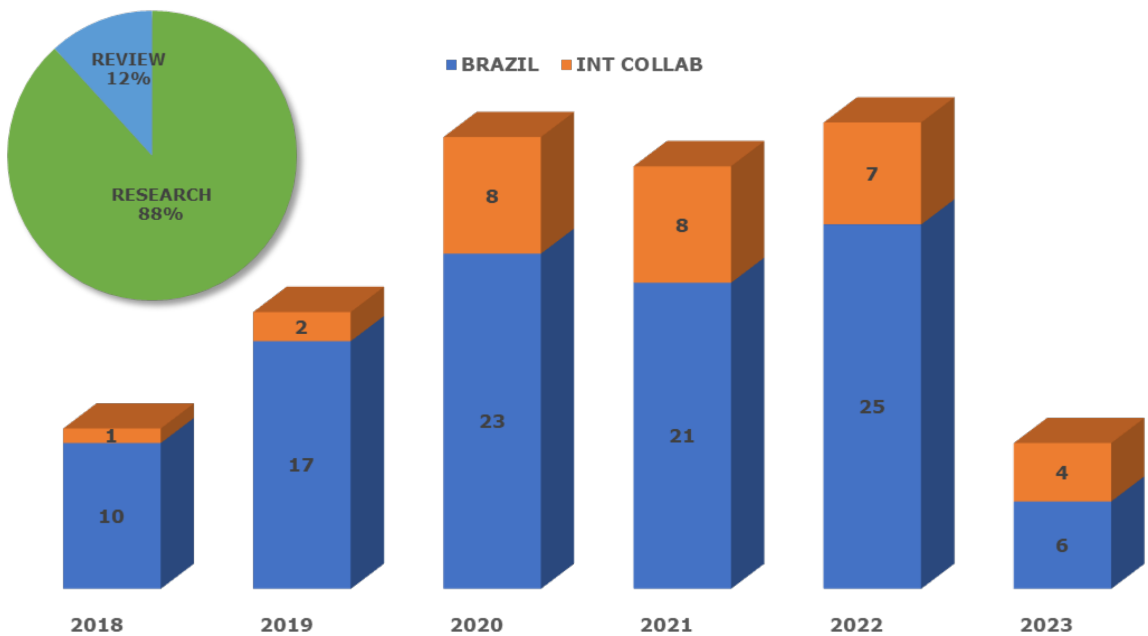


Figure 2 – Number of articles published/year on microplastics in Brazilian coastal environments independently and with international collaboration (n=102).

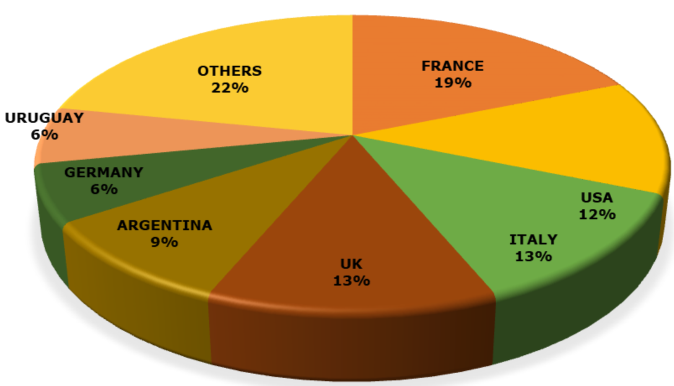


Figure 3 – Countries that collaborated with Brazilian researchers in studies on microplastics in Brazilian coastal environments.

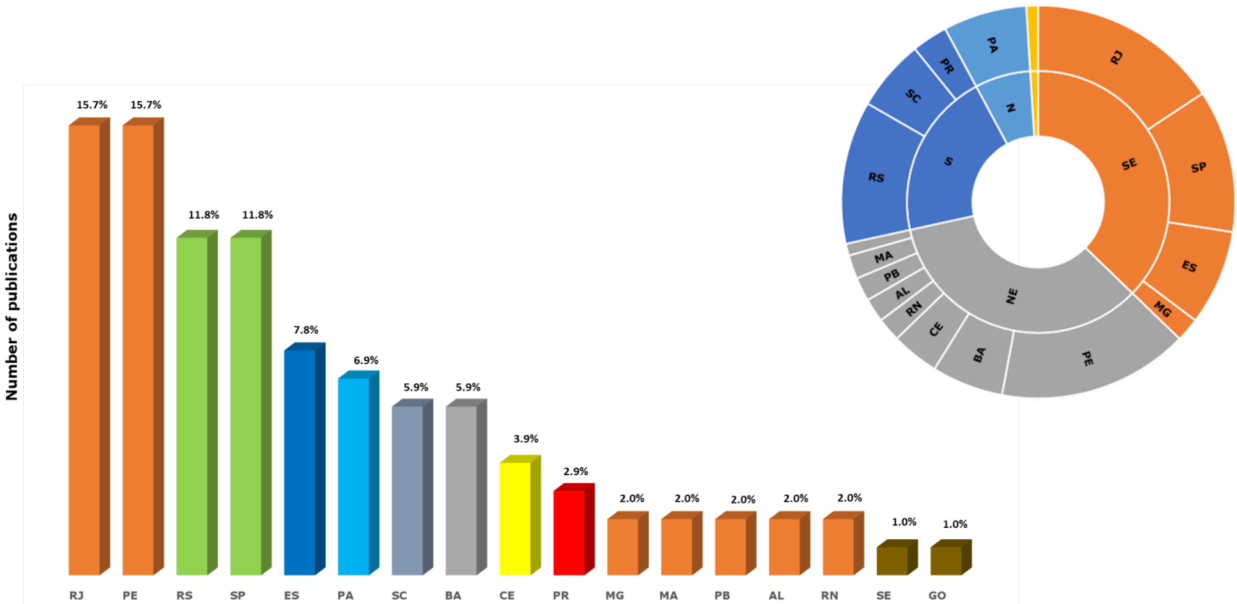
with 15.7% of the articles followed by Bahia (5.9%) and Ceará (3.9%). Among the states in the Southern region, Rio Grande do Sul presented the largest number of articles (11.8%), followed by Santa Catarina (5.9%) and Paraná (2.9%). Finally, 7% and 1% of publications were carried out by the states of Pará and Goiás, North and Midwest regions, respectively. Considering the 17 Brazilian states with a coastal region, only Amapá and Piauí did not publish any work on the subject in this period.

In the research national scenario, some changes were observed in relation to Castro et al. (2018) once in this study most of the scientific publications were produced by researchers from Pernambuco and São Paulo states. In the current research, the state of Rio de Janeiro reaches Pernambuco in a number of publications in the period between 2018 and 2023. The number of researches coming from Rio Grande do Sul is also noteworthy, which was not observed until 2017. These data show that the scientific topic about MPs in coastal environments (beaches, mangroves, and estuaries) has gradually reached greater relevance among institutions and research groups across the country.

The distribution of teaching and research institutions involved in the publications was also the subject of analysis in this work. The institution of the corresponding author was considered responsible for the research and when there was more than one corresponding author and they were from different institutions, the affiliation of the last author of the work was considered. A total of 102 publications were assigned to 38 Brazilian institutions (Figure 5) that correspond to only 1.46% of the total number of higher learning institutions (2,595) in Brazil (Brasil, 2022).

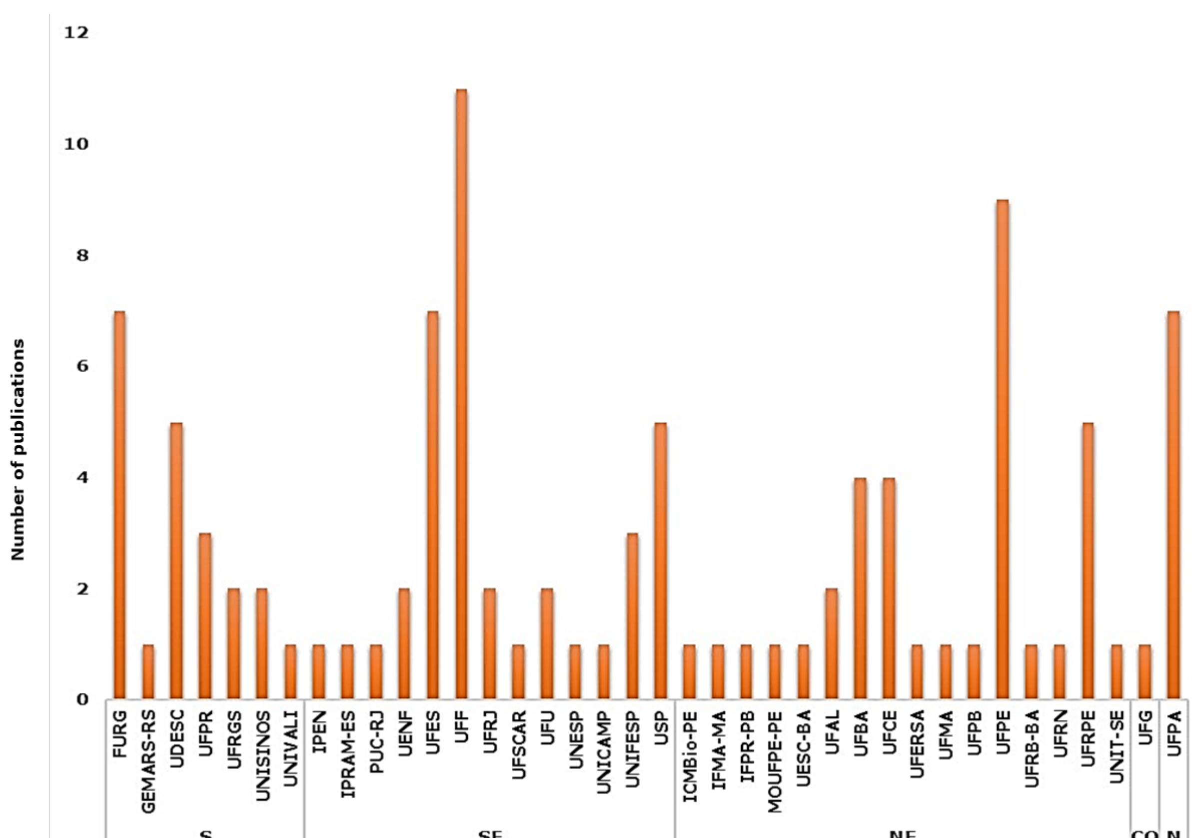
Among the institutions that contributed with more than five publications, the Fluminense Federal University (UFF) stands out with 10.8% of the researches published during the period analyzed followed by the Federal University of Pernambuco (UFPE, 8.8%), the Federal University of Rio Grande (FURG, 6.9%), the Federal University of Espírito Santo (UFES, 6.9%), the Federal University of Pará (UFPA, 6.9%), the State University of Santa Catarina (UDESC, 4.9%), the University of São Paulo (USP, 4.9%), and the Federal Rural University of Pernambuco (UFRPE, 4.9%). Until 2017, USP and UFPE had been the institutions with the highest number of publications, according to Castro et al. (2018).

Regarding the coastal environments studied in each Brazilian state, the distribution of studies is not uniform (Figure 6). The Northeast region, which has the most extensive coastal strip, contributed 36.9% of monitoring research in the period 2018–2023, but only the Pernambuco state is among the five most states studied.



RJ: Rio de Janeiro; PE: Pernambuco; RS: Rio Grande do Sul; SP: São Paulo; ES: Espírito Santo; PA: Pará; SC: Santa Catarina; BA: Bahia; CE: Ceará; PR: Paraná; MG: Minas Gerais; MA: Maranhão; PB: Paraíba; AL: Alagoas; RN: Rio Grande do Norte; SE: Sergipe; GO: Goiás; regions — N: North; NE: Northeast; S: South; SE: Southeast; and CO: Midwest).

Figure 4 – Brazilian states and regions of the teaching and research institutions that published between 2018 and 2023 (n=102).



N: North; NE: Northeast; S: South; SE: Southeast; CO: Midwest.

Figure 5 – Brazilian teaching and research institutions (by Brazilian region) that published the most between 2018 and 2023 (n=102).

Table 2 – Journals with publications on microplastics in Brazilian coastal environments between 2018 and 2023.

Journal	n	%	IF	DB
Marine Pollution Bulletin	49	48.0	5.8	SD
Science of the Total Environment (STOTEN)	11	10.8	9.8	SD
Environmental Pollution	9	8.8	8.9	SD
Regional Studies in Marine Science	4	3.9	2.1	SD
Environmetal Science and Pollution Research	3	2.9	5.8	SP
Ocean & Coastal Management	3	2.9	4.6	SD
Environmental Research	2	2.0	8.3	SD
Frontiers in Environmental Science	2	2.0	4.6	FT
Ocean and Coastal Research	2	2.0	0.8	WOS
Archives of Environmental Contamination and Toxicology	1	1.0	3.6	SP
Environmental Monitoring and Assessment	1	1.0	3.3	SP
Food Webs	1	1.0	1.7	SD
Frontiers in Marine Science	1	1.0	5.2	FT
International Aquatic Research	1	1.0	2.2	SP
Journal of Coastal Research	1	1.0	0.8	SP
Journal of Engineering and Technological Sciences	1	1.0	1.2	SCP
Journal of Hazardous Materials	1	1.0	14.2	SD
Journal of Polymers and the Environment	1	1.0	4.7	SP
Journal of the Brazilian Chemical Society	1	1.0	2.1	WOS
Marine Environmental Research	1	1.0	3.6	SD
MethodsX	1	1.0	1.9	SD
Oecologia Australis	1	1.0	0.2	SCP
Revista Brasileira de Pesquisa em Turismo	1	1.0	0.5	SCL
Revista Virtual de Química	1	1.0	0.1	WOS
Thalassas	1	1.0	0.3	SP
Waste Management	1	1.0	8.8	SD

n: number of articles; IF: impact factor; DB: database where the journal is indexed; SD: Science Direct; SP: Springer; WOS: Web of Science; SCL: SciELO; FT: Frontiers; SCP: Scopus.

The state of Bahia, which has the longest coastline in the country (932 km, 12.4% of the total coastal strip), followed by Maranhão (640 km, 8.7%) together accounted for only 9.9% of the environments studied. The Southeast region stands out with 36% of the studies, and among the three states in the South region, Santa Catarina and Rio Grande do Sul together corresponded to 17.1%.

Regarding the coastal environments studied, 70% of the studies considered evaluated the presence of MPs on beaches, whether sandy or rocky, on coastlines, islands, archipelagos or in bays. Mangroves corresponded to 26% of publications, 2% of estuaries, and 2% of coral reefs (Figure 7). Different matrices were evaluated for the presence, abundance, and morphotypes of MPs. Research that analyzed MPs in marine biota corresponded to 43% of the publications, followed by sediment (42%), water (14%), and other matrices, such as rocky outcrops on beaches. The most studied organisms were boney fish (42%), followed by bivalves (17%), crustaceans (7%), seabirds (7%), turtles (7%), and microfauna (5%).

Studies that evaluated the presence of MPs in marine and estuarine organisms have been predominant among national publications since 2009 to the present (Castro et al., 2018). Although ingestion of MPs rarely causes mortality, showing less influence on survival rate, several studies report that exposure inhibits many enzymatic and metabolic pathways in invertebrates and vertebrates (Anbumani and Kakkar, 2018). Most global studies have been concerned with analyzing the effects of MPS intake at the individual level, combining effects at the cellular and subcellular levels (Galloway et al., 2017).

Of the 120 publications compiled in this work, 90 consist of field research, of which 33 used some technique to characterize and/or confirm the polymeric composition of MPs. This characterization was carried out in both biological and abiotic matrices.

Figure 6 – Percentage of environments studied by state with publications from 2018 to 2023.

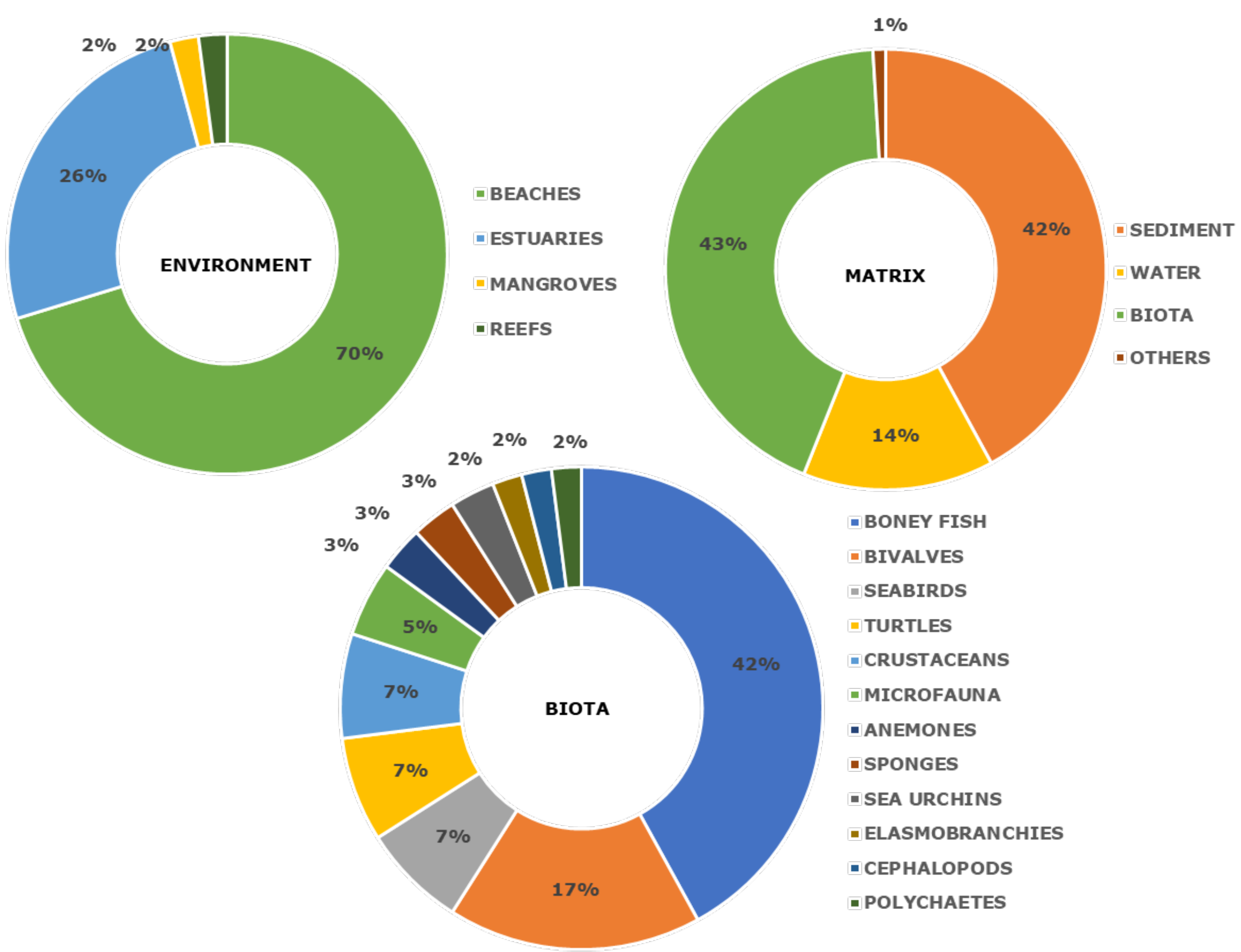


Figure 7 – Percentage of articles published on microplastics in Brazilian coastal environments between 2018 and 2023 in relation to the environments, matrices, and organisms analyzed.

Among the spectroscopic techniques currently available, the most used were as follows: Fourier transform infrared (FTIR) spectroscopy (22.2%), direct laser infrared (DLIR, 3.3%), Raman (3.3%), and electronic microscopy scanning coupled to electron dispersion spectroscopy (EMS/EDS, 1.1%). Differential thermal analysis with thermogravimetric analysis (DTA/TGA) was used in 1.1% of the studies. As a complementary technique for confirming the plastic composition, the hot needle technique was used in 4.4% of publications.

Presence of microplastics in Brazilian coastal environments

A summary of the MP monitoring studies in coastal environments evaluated in the present work is presented in Supplementary Table S1. MPs are present in all coastal environments studied, including marine protected areas (MPAs), which were conceived and planned as a conservation strategy. Nunes et al. (2023) presented an overview of the occurrence, abundance, and distribution of MPs that potentially affect MPAs globally, using data from previous studies on sediment and biota samples and tracking the localities using geographic information systems (GIS). MPs were found in 186 MPAs with levels of up to 9,187 items/kg in sediment and up to 17,461 items/kg in marine biota. Maximum concentrations of MPs occurred in areas of multiple uses, but MPAs more restricted to human access were also affected, including two reported in Brazil, the ecological stations of Guaraqueçaba and Ilha do Mel (Vieira et al., 2021).

The continuous input of plastic waste into oceanic and coastal environments has reached alarming levels that are posing new exposures to natural systems (Fundação Heinrich Böll, 2020). Santos et al. (2022) investigated the occurrence of multiple associated plastic debris in a volcanic outcrop (Trindade Island, ES) which corresponds to one of the most remote regions of the Brazilian coast and, since 1957, has been protected by the Brazilian Navy. The plastic debris consisted of the association of polypropylene and polyethylene (PE), which was correlated in a depositional system model, which suggests that the plastic debris forms are synthetic equivalents of rocks in which humans act as depositional and post-depositional agents.

Regarding multiple-use MPAs, MPs were found in the environmental protection areas (EPAs) of Fernando de Noronha/RN (Carvalho et al., 2021; Ferreira et al., 2023) and Guaraqueçaba/PR (Vieira et al., 2021) and estuarine complex in Vitória Bay/ES (Zamprogno et al., 2021) and São Sebastião/SP (Tsukada et al., 2021). Around half of the MPAs analyzed presented concentrations of MPs considered high and with potential impacts. In relation to biota, benthic species were more affected than pelagic ones, with higher concentrations of MPs in their tissues. The results denote urgent concerns about the effectiveness of the global protected areas system and its proposed conservation objectives.

The Mengatto and Nagai study (2022) presented the evaluation of MPs in drift sediments from nineteen sandy beaches in the Paranaguá Estuarine Complex, in southern Brazil, where the country's second-largest grain port is located, the EPA of Guaraqueçaba and the Guaraqueçaba Ecological Station. Almost all of the beaches sampled presented contamination by MPs, which was attributed to urban and port activities in the region. A total of 398 MP particles were found, of which the majority were foams (63.7%), rigid plastic fragments (13.8%), paint fragments (12.8%), and pellets (7.2%).

The presence of MPs in the environment represents a marker of emerging contamination. Alves et al. (2023) analyzed the vertical distribution of PMs in six sediment cores obtained in the Patos-Mirim System (RS), the largest coastal lagoon system in the world. The sediment cores were located near urban/industrial and agricultural regions. The predominant format of MPs was fiber, followed by fragments. The most commonly identified polymers were rayon, PVC, acrylate, and polycarbonate. Furthermore, MPs are collectively a reliable indicator of the beginning of the Anthropocene, and in the Patos-Mirim System, the most appropriate chronology can be attributed to the beginning of the 1970s, corresponding to the intensification of anthropogenic activities in the area (Alves et al., 2023).

Estuaries are known to provide essential goods (raw materials and food) and an attractive environment for population growth and cultural activities. In addition, they perform important ecological functions, as fish use these environments for protection, feeding, reproduction, settlement, and nursery (Ferreira et al., 2019). Around the world, estuaries are typically surrounded by large metropolises, and the expansion of the urban population is directly associated with impacts on coastal ecosystems (Freeman et al., 2019; Justino et al., 2021).

MPs are a relevant environmental concern in marine ecosystems; however, knowledge about dispersal patterns and interaction with biota is scarce and mainly limited to surface water. Studies monitoring the presence of MPs in deep-sea species can provide an idea of the level of contamination in the water column in oceans. Ferreira et al. (2023) investigated contamination by MPs in the digestive tract of mesopelagic lanternfish (n=364 individuals) from the northeast coast and remote regions (Atol das Rocas and Fernando de Noronha) captured between 90 and 1000 m depth. MPs were detected in 68% of the individuals analyzed. Filaments were the most frequent, followed by fragments and foams. MPs consisting of high-density polymers such as styrene-butadiene rubbers (SBS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polyamide (PA) were more prevalent than low-density ones such as polybutadiene rubber (BR), PE, and ethylene vinyl acetate (EVA), especially in deeper layers. In 2018, a decree was published prohibiting the use and sale of single-use plastics on the island. However, these results highlight the urgent need for socio-environmental programs, mainly aimed at tourists and beach users, reinforced inspection and integrated prevention strategies to tackle the issue of marine litter around the world and, thus, reduce its accumulation, production, and impacts on the environment (Grillo and Melo, 2021).

A similar study was carried out with two species of deep-sea cephalopods from the Southwest Atlantic with different ecological behavior: the vampire squid (*Vampyr oteuthis infernalis*) and the intermediate squid (*Abralia veranyi*) (Ferreira et al., 2022). The organisms were collected in an area that covered the Fernando de Noronha Archipelago, Rocas Atoll, and adjacent seamounts. Although it was found that most specimens were contaminated by MPs, *V. infernalis* showed higher levels of contamination (9.58±8.25 particles per individual) than *A. veranyi* (2.37±2.13 particles per individual), probably due to their dietary strategy. The size of the extracted MPs was inversely proportional to the foraging depth and the particles were heterogeneous in shape, color, and polymer type.

Pegado et al. (2018) investigated the occurrence of MPs in the digestive tract of fish from the Amazon River estuary, the first evidence of MP contamination of biota in this environment and on the north coast of Brazil. A total of 189 fish specimens representing 46 species from 22 families were sampled from shrimp fisheries bycatch. In total, 228 MPs were found from the gastrointestinal tract of 26 specimens belonging to 14 species (30% of the individuals examined). MPs were categorized as pellets (97.4%), sheets (1.3%), fragments (0.4%), and filaments (0.9%) with sizes ranging from 0.38 to 4.16 mm. The main polymers identified were PA, rayon, and PE.

In addition to species representing remote and environmentally protected areas, recent studies reveal the presence of MPs in seafood frequently consumed in the human diet. Bom and Sá (2022) identified MPs in four important bivalve species traded in Brazilian markets. The origin of each species included in the study was different: oysters (*Crassostrea gigas*) were cultivated in the state of Santa Catarina and sold in the shell, frozen and without prior treatment; mussels (*Mytilus chilensis*) were imported from Chile, sold shelled, cooked, and frozen; *Perna pera* were grown in Guarapari-ES and were also sold without prior treatment (whole and fresh); and *Placopten magellanicus* scallops were imported from Peru and were also sold peeled and frozen. The presence of MPs was identified in all bivalves, with an average concentration of 1.64 MPs/g and 10.69 MPs/individual. The authors concluded that bivalves are a source of MPs for the Brazilian population and new studies should evaluate other species sold in different regions of the country.

Identifying the sources of plastic in the environment is crucial for defining environmental management strategies. In this sense, some of the works analyzed sought, through their results, to support actions to reduce sources of marine litter and conservation and sustainable use of the oceans and marine resources, as defined in SDG 14 of the United Nations (UN). Silva et al. (2022) quantified and characterized marine debris and MPs in the sands of beaches in the Oceanic Region of Niterói and evaluated beach cleanliness using the Clean Coast Index (ICL). Niterói has its beaches as tourist attractions and waste management is a major challenge of the current municipal strategic plan (2013–2033).

Pinheiro et al. (2021) quantified the marine litter captured by trammels in the surf zone, a type of artisanal fishing used in the coastal zone of southern Brazil. In addition, teaching material was prepared for social inclusion actions. A doll was produced with marine debris collected from the nets and was present at six events between 2018 and 2020. At these events, around 5,600 people came into contact with the doll and the message transmitted by the activity facilitators. Informative material with the main results of the study was delivered to collaborating fishermen, entities linked to fishing activities in the State of Rio Grande do Sul, and the academic community.

Literature review studies have helped to define the recent scenario of MP research in Brazil, identifying subjects that have not yet been studied, in order to guide future research to fill these gaps. Literature review articles that were published during the period 2018–2023 are compiled in Supplementary Table S2.

Studies of MPs in Brazilian coastal environments have been carried out mainly on beaches, and the matrices most analyzed in recent years are biota and sediment (Fernandes et al., 2022; Oliveira et al., 2023). The highest levels of MPs were observed in regions with high population density, but remote and restricted-access environments also recorded the presence of MPs. Articles retrieved in the systematic search for literature on MPs in Brazilian coastal environments and classified in a different scope from other studies in the data group for the period from 2018 to 2023 are presented in Supplementary Table S3.

Conclusions

This review aimed to evaluate the recent Brazilian scenario (2018–2023) in relation to the state of the art in research with MPs in coastal environments, including beaches, mangroves, estuaries, and reefs. The main databases that index journals with a high impact factor were accessed, with the aim of collecting the main articles published on the topic during this period.

In recent years, research involving the topic of MPs has gained global prominence. However, in Brazil, the distribution of locations investigated in the most recent studies shows that most are concentrated in the Southeast and Northeast regions, with emphasis on the states of Rio de Janeiro and Pernambuco. Regarding the origin, the work compiled in this study infers that the main sources of MPs are tourism, fishing, and river discharge, while the action of waves and winds contributes to the dispersion of these particles to less urbanized beaches and remote locations. However, the identification of patterns and processes of contamination of Brazilian beaches by MPs faces methodological inconsistencies, such as the lack of standardization of measurement units, collection methods, and sample preparation. In addition, the ecological effects of the incorporation of MPs by biota have been little addressed in the literature.

The presence and persistence of MPs in the marine environment cause several impacts that require further investigation for a better understanding. Based on the scenario of current studies and available literature, we found that there are challenges to be overcome in understanding the occurrence, distribution, prevalence, and environmental impact of MPs. Only with increasing knowledge about various aspects related to MPs, it will be possible to understand their implications and establish propositions on mitigation strategies, management, treatment, and related public policies. In this sense, there is a need to improve studies in relation to the causal link (typology of anthropogenic activities and population density, among others) and the influence of environmental factors (tides, winds, and sea currents) in places with different types of territorial occupation (both coastal metropolises as well as small caiçara villages and places of tourist activities).

At a global level, a major challenge is the development of studies on a larger spatial and temporal scale and the need to gather information that can support the construction of models capable of detecting the behavior of plastics in ecosystems, identifying their possible source, dispersion, abundance, and degradation time. In Brazil, despite important advances in the area of sandy beach ecology and human impacts on these ecosystems, some questions still remain unanswered regarding the process of deposition and dispersion of MPs. Therefore, new information about deposition and predictors of beach contamination by MPs can be generated from unified sampling protocols and synchronized research directions, enabling comparative and quantitative analyses of the contamination of coastal environments by MPs in different regions of the country. Finally, the Brazilian Ministry of the Environment recently created the "National Plan to Combat Litter at Sea" (Brazil, 2019), which recommends carrying out research on plastics on the Brazilian coast.

Authors' Contributions

Escrobot, M.: methodology, investigation, writing – original draft, Writing - review & editing. Pagioro, T.A.: methodology, data curation, validation, writing - review & editing. Martins, L.R.R.: conceptualization, validation, writing - review & editing, supervision. Freitas, A.M.: conceptualization, validation, writing - review & editing, supervision, funding, acquisition.

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