

*Ciencia e Ingeniería*Revista Interdisciplinar de Estudios en Ciencias
Básicas e Ingenierías

ISSN 2389-9484

Año 2026, julio-diciembre, Vol. 13, N.º 2, e21060780

Facultades de Ciencias Básicas y Aplicadas e

Ingeniería. Universidad de La Guajira

La Guajira, Riohacha, Colombia

<http://revistas.uniguajira.edu.co/index.php/cei>

Este documento fue depositado en Zenodo.

DOI: <https://www.doi.org/10.5281/zenodo.21060780>ARK: <https://n2t.net/ark:/60540/21060780>**Adriana Carolina Gamboa***<https://orcid.org/0000-0003-1828-4219>adrianacgam@gmail.com

Universidade Federal de Goiás, Goiânia, GO, Brasil

Universidade Federal de Santa Maria, FW, RS, Brasil

Sailer Santos dos Santos<https://orcid.org/0000-0002-7086-8871>sailer.santos@ufsm.br

Universidade Federal de Santa Maria, Santa Maria,

RS, Brasil

Andressa Maiara de Almeida Machado<https://orcid.org/0009-0005-4475-0828>andressa.mnunes@gmail.com

Universidade Federal de Santa Maria, FW, RS, Brasil

Kauane Andressa Flach<https://orcid.org/0000-0001-8915-3289>kaauane_flach@hotmail.com

Universidade Federal de Santa Maria, SM, RS, Brasil

Genesio Mario da Rosa<https://orcid.org/0000-0003-1247-2286>genesiomario@yahoo.com.br

Universidade Federal de Santa Maria, FW, RS, Brasil

Fábio Marcelo Breunig<https://orcid.org/0000-0002-0405-9603>fabio-breunig@ufpr.br

Universidade Federal de Paraná, Curitiba, PR, Brasil

*correspondencia.

CHARACTERIZATION OF MACRO-, MESO-, AND MICROPLASTICS ON THE HIGH-TIDE LINE OF BOA VIAGEM BEACH, RECIFE, BRAZIL

Caracterización de macro, meso y microplásticos en la línea de marea de la playa Boa Viagem, Recife, Brasil

ABSTRACT

Plastic pollution in coastal ecosystems remains a critical environmental challenge with implications for biodiversity, ecosystem integrity, and human well-being. This study presents a size-based characterization of plastic contaminants stranded along the high-tide line of a sector of Boa Viagem Beach (Recife, Brazil), integrating the assessment of macro-, meso-, and microplastic fractions with polymer identification in a subset of particles. A composite 1 kg sample collected along a 100 m stretch of the high-tide line was processed through a two-phase procedure involving size fractionation by sieving followed by density separation to improve plastic recovery. Macroplastics were classified according to size, color, and probable source categories, whereas meso- and microplastics were characterized based on morphology and color. Polymeric composition of selected meso- and microplastics was determined using confocal Raman spectroscopy. A total of 110 macroplastics, 237 mesoplastics, and 185 microplastics recovered during sieving were recorded, together with 49 potential plastic particles recovered after density separation. Macroplastics were mainly associated with urban, recreational, and fishing-related activities, particularly bottle caps and cigarette butts. Meso- and microplastic fractions were dominated by fragments and foams. Among the particles successfully identified by Raman spectroscopy, polystyrene, polyethylene, and polypropylene were detected. The results provide a preliminary baseline of plastic size distribution, morphological characteristics, and polymer composition for this urban tropical beach sector, contributing reference information for future monitoring efforts and locally oriented management strategies.

Keywords: plastic pollution; microplastics; plastic litter; urban beach; polymer composition; Raman spectroscopy.

RESUMEN

La contaminación por plásticos en ecosistemas costeros representa un desafío ambiental crítico con implicaciones para la biodiversidad, la integridad de los ecosistemas y el bienestar humano. Este estudio presenta una caracterización basada en tamaño de contaminantes plásticos depositados a lo largo de la línea de marea en un sector de la playa Boa Viagem (Recife, Brasil), integrando la evaluación de macro, meso y microplásticos con la identificación de polímeros. Se procesó una muestra compuesta de 1 kg recolectada a lo largo de un tramo de 100 m de la línea de marea alta mediante un procedimiento en dos fases: fraccionamiento por tamaño mediante tamizado seguido de separación por densidad para mejorar la recuperación de partículas plásticas. Los macroplásticos fueron clasificados según tamaño, color y fuente probable, mientras que los meso y microplásticos se caracterizaron por su morfología y color. La composición polimérica de partículas seleccionadas se determinó mediante espectroscopia Raman confocal. Se registraron 110 macroplásticos, 237 mesoplasticos y 185 microplásticos recuperados durante el tamizado, además de 49 partículas potencialmente plásticas recuperadas mediante separación por densidad. Los macroplásticos estuvieron asociados principalmente con actividades urbanas, recreativas y pesqueras, especialmente tapas y colillas de cigarrillos. Las fracciones de meso y microplásticos estuvieron dominadas por fragmentos y espumas. Entre las partículas identificadas mediante Raman se detectaron poliestireno, polietileno y polipropileno. Los resultados proporcionan una línea base preliminar para futuros programas de monitoreo y estrategias de gestión local.

Palabras clave: contaminación plástica, microplásticos, residuos plásticos, playa urbana, composición de polímeros, espectroscopia Raman.

Recibido: 19-02-2026

Aceptado: 19-05-2026

Publicado: 01-07-2026



INTRODUCTION

Plastic pollution has emerged as one of the most persistent environmental challenges of the Anthropocene, profoundly affecting marine and coastal ecosystems and posing serious risks to biodiversity and human health (Ma et al., 2020; García-Muñoz et al., 2023). Each year, an estimated 8-12 million tons of plastic waste enter the oceans where it accumulates, alters habitat structure, and disrupts ecological processes (Borrelle et al., 2020). Once released, plastic litter fragments into progressively smaller particles: mesoplastics, microplastics (MPs), and nanoplastics (NPs), which are easily dispersed by wind or currents and may be incorporated into food webs, leading to adverse biological effects (Andrady, 2017; Jambeck et al., 2015).

Plastics represent more than 80% of marine litter in coastal environments, and tend to accumulate on sandy beaches and intertidal zones (Lebreton et al., 2018). According to GESAMP (2019), plastic litter is classified into megaplastics (>1 m), macroplastics (25-1000 mm), mesoplastics (5-25 mm), microplastics (MPs; <5 mm), and nanoplastics (NPs; <1 µm). Because of their small size and persistence, MPs and NPs can be ingested by a wide range of marine organisms, including zooplankton (Rodríguez-Torres et al., 2024), fish, turtles and mammals (Zazouli et al., 2022; Gündoğdu et al., 2024; Kimura et al., 2024), facilitating their entry and biomagnification in the food chain (Ma et al., 2020; Gündoğdu et al., 2024). MPs act as vectors for other contaminants such as metals, pesticides, and pharmaceuticals, enhancing their transport and bioavailability (Sheng et al., 2021; Bagheri et al., 2024). They can also carry pathogens, fungi, and invasive species (Casabianca et al., 2019; Silva et al., 2021).

Global initiatives, such as the United Nations Environment Programme's (UNEP) Global Partnership on Marine Litter (GPML) and the 2022 Global Plastics Treaty negotiations, emphasize the urgent need to reduce plastic leakage into aquatic environments through evidence-based monitoring and policy integration. In this context, local studies that quantify and characterize plastic pollution provide essential data to know the state of specific ecosystems and thus be able to contribute to the design of local management strategies, which can have an impact at a global level, if actions are taken in different localities.

In Latin America, MPs pollution in coastal environments has been increasingly documented. For example, Zarate & Iannacone (2021) reported high concentrations of MPs on sandy beaches in Peru, particularly in areas affected by urban discharges and intense tourism. Similarly, Cruz-Salas et al. (2020) found large quantities of MPs on Zipolite Beach, Mexico, mainly composed of synthetic fibers and anthropogenic plastic fragments. In protected coastal areas of the Colombian Caribbean, MPs have been reported in mangrove and beach environments, suggesting that limitations in waste management may be associated with their accumulation (Garcés Ordóñez, 2022). Brazil is ranked as the fourth-largest producer of plastic waste globally, generating approximately 11,3 million tonnes annually, of which less than 2% is effectively recycled (WWF, 2019; Pelegrini et al., 2024). As a result, the accumulation of plastic litter and MPs in Brazilian coastal zones has become a growing environmental concern (Do Amparo et al., 2023).

Boa Viagem Beach (Recife, PE, on Brazil's northeastern coast) has been reported as an urban coastal area exhibiting notable levels of plastic contamination. Previous investigations have

documented the presence of both virgin plastic pellets (primary MPs) and fragmented plastics (secondary MPs) along the tidal zone, with reported average abundances of approximately 0,01 pellets and 0,29 plastic fragments per square centimeter, covering size ranges from <1 mm to 20 mm (Costa et al., 2010; Pinheiro et al., 2019). However, these studies mainly focused on particle abundance and size distribution, providing limited information on the classification of larger plastic litter and lacking polymer-specific characterization of meso- and microplastic fractions. The objective of this study was to provide a descriptive, size-based characterization of plastic litter accumulated along the high-tide line of a sector of Boa Viagem Beach (Recife, northeastern Brazil). Specifically, the study aimed to (i) quantify and classify macroplastic items according to type, (ii) characterize meso- and microplastic based on size, shape, and color, and (iii) identify the polymer composition of a selected subset of meso- and microplastic particles using confocal Raman spectroscopy. The resulting dataset constitutes baseline information on plastic size distribution and polymer composition for this urban coastal sector, supporting future monitoring efforts and comparative assessments.

MATERIALS AND METHODS

Study Area

Boa Viagem Beach is in the southern coastal zone of Recife, Pernambuco State, northeastern Brazil (Figure 1). Spanning approximately 8 km, the beach is mostly straight and bordered to the south by coordinates 08° 08' 55" S and 34° 54' 24" W, and to the north by 08° 06' 06" S and 34° 53' 04" W. As the city's principal ocean-facing beach, it lies within a densely urbanized area. Historically, this region formed part of a broader coastal ecosystem that included dunes, lagoons, mangroves, and small rivers; however, rapid urbanization has significantly reduced these natural habitats. The beach serves both ecological and recreational functions, providing shoreline protection, local climate regulation, and providing nesting habitat for sea turtles, while also acting as a major tourist destination. Although designated as a Special Environmental Protection Zone since 2001, the area faces weak enforcement, resulting in the accumulation of solid waste, coastal erosion, and increasing anthropogenic pressure (Costa et al., 2008). The coast of Pernambuco is wave-dominated and mesotidal, influenced by prevailing trade winds that blow predominantly from the east-southeast during winter (April-September) and from the east-northeast in summer (October-March). The nearshore zone is characterized by sandstone reef outcrops (beachrocks) that are more continuous in the northern portion of the beach and become discontinuous toward the south. These features modulate wave energy and sediment transport, generating alternating protected and exposed zones that influence the retention of floating and stranded debris (Costa et al., 2008; de Gois et al., 2013).

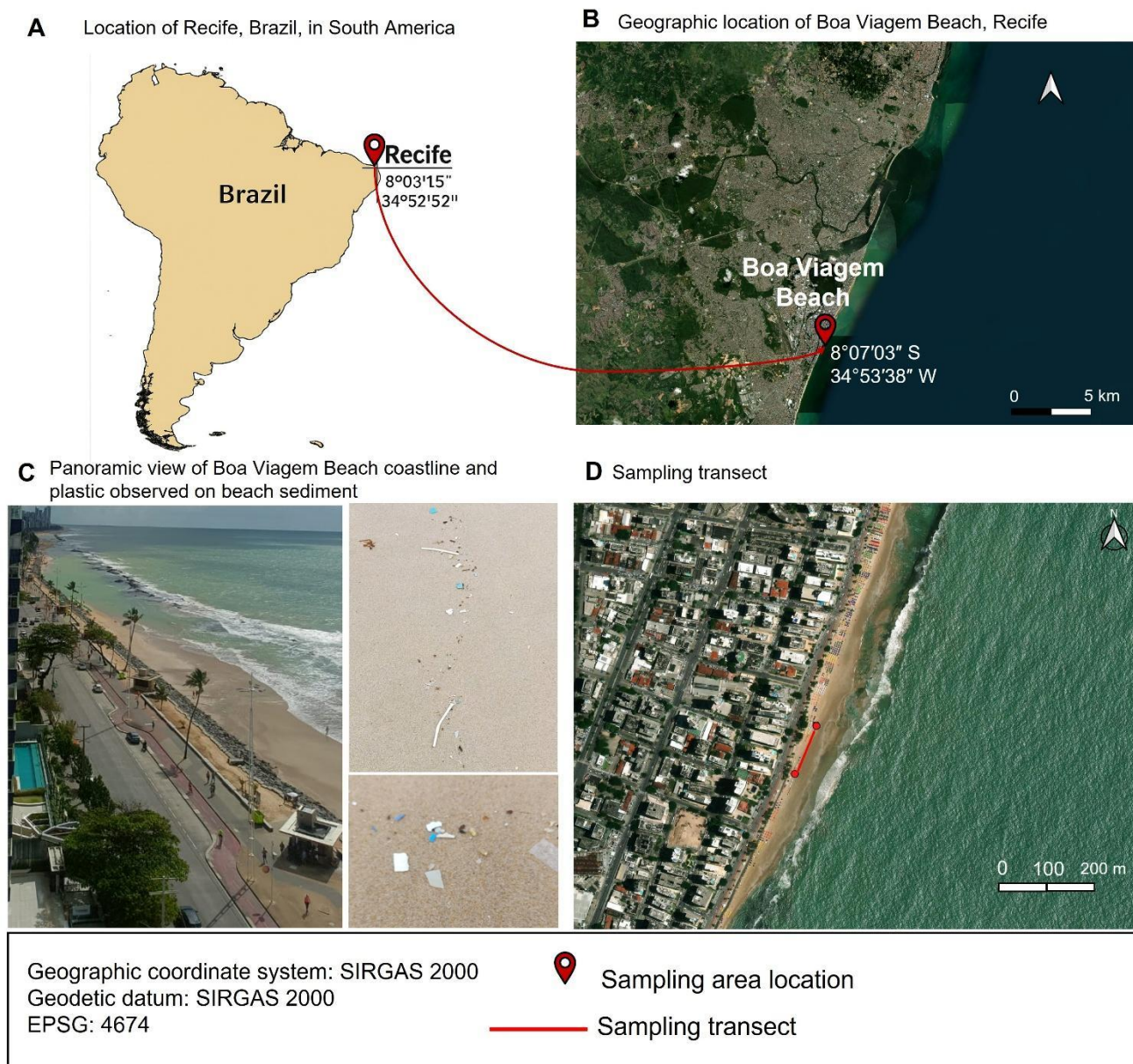


Figure 1. Study area and field observations at Boa Viagem Beach, Recife, Brazil. (A) Location of Recife in Brazil. (B) Geographic location of Boa Viagem Beach. (C) Panoramic view of the coastline and plastics observed in sediments. (D) Satellite image showing the sampling transect.

Sedimentologically, Boa Viagem Beach shows high uniformity in texture and composition, with the foreshore composed predominantly of fine quartz sand mixed with bioclastic material. The width of the beach varies considerably along the Boa Viagem-Pina coastal system. The northern portion, corresponding to Pina Beach, exhibits a broader and relatively stable foreshore, while the central and southern areas of Boa Viagem Beach are markedly narrower and subject to active erosion processes (Gregório et al., 2004; de Gois et al., 2013; Gregório et al., 2017).

Sampling

In early September 2024, a 100 m transect was established along the high-tide line of Boa Viagem Beach (8°07'03" S; 34°53'38" W). A continuous sweep was performed to collect one composite sample of surface sediments and plastic litter (1 kg). The composite sample approach was adopted to obtain an integrated representation of plastic contamination along the selected high-tide sector. The sampling site was located in the southern portion of Boa Viagem Beach, within a coastal stretch between Coronel Benedito Chaves Street and Bruno Veloso Street. This area is characterized by a moderately wide back-beach bordered by a well-defined high-tide scarp and by a more developed line of sandstone reef outcrops offshore, and corresponds to the erosional sector previously described by Gregório et al. (2017). The study site was selected based on its geomorphological setting and exposure conditions, corresponding to a high-energy sector of Boa Viagem Beach characterized by erosive features and discontinuous beachrock formations. This sector is additionally influenced by adjacent urban activities, making it suitable for documenting the characteristics of plastic litter stranded along the high-tide line. The transect was established to generate baseline, site-specific information intended to support future multi-site and comparative monitoring of coastal plastic contamination along Boa Viagem Beach.

Plastic separation and density treatment

First phase

After drying at room temperature, the collected material was processed to separate plastic particles (macro-, meso-, and microplastics) from the sediment matrix. Macroplastics (25-1000 mm) and mesoplastics approaching the upper size limit (~25 mm) were manually removed from the sample and reserved for subsequent classification. The remaining sample was sieved using stainless-steel meshes with aperture sizes of 2.00; 1.00; 0.25 and 0.149 mm. This procedure enabled the segregation of sediments and plastic particles into five size fractions: F1 (>2.00 mm), F2 (2.00-1.00 mm), F3 (1.00-0.25 mm), F4 (0.25-0.149 mm), and F5 (<0.149 mm; material passing through and collected below the smallest sieve aperture). Sediment fractions obtained through sieving were weighed and classified according to the Wentworth grain-size scale using the mesh aperture sizes employed in this study. The relative proportion of each sediment fraction was calculated from the dry mass retained on each sieve and expressed as a percentage of the total sediment mass. Because the smallest mesh aperture employed was 0.149 mm, a detailed discrimination of finer fractions such as silt and clay was not possible. Subsequently, each fraction was visually examined for the separation of meso- and microplastics using tweezers. The mesoplastics obtained from the sieving process were added to those initially separated from the original sample. It should be noted that although particles smaller than 1 mm were retained during sieving, their visual identification and manual separation were limited due to their reduced size.

Second phase

In the second stage, all sediment fractions obtained after the initial sorting procedure (First phase) were subjected to additional processing to improve the extraction of plastic particles retained within the sediment matrix. Although all fractions were processed, this complementary

approach was particularly important for the smaller size fractions, where the visual identification and manual separation of particles become increasingly limited, thereby improving the detection and recovery of plastics not readily observable during the first phase. To remove organic matter, each sediment fraction was processed in successive 50 g portions, with each portion treated with 30 mL of 30% hydrogen peroxide (H_2O_2) and allowed to react for 72 h at room temperature until the entire sample had been analyzed. Following digestion, a saturated sodium chloride (NaCl) solution (5 M; $\rho = 1.15 \text{ g mL}^{-1}$) was added for density separation (Masura et al. 2015). The suspension was allowed to settle for 24 h, and the supernatant was then vacuum-filtered through $0.45 \mu\text{m}$ mixed cellulose ester (MCE) filters. This combined chemical and physical separation allowed the recovery of low-density polymers ($\rho < 1.15 \text{ g mL}^{-1}$), such as polyethylene (PE: HDPE, high-density polyethylene, or LDPE, low-density polyethylene), polypropylene (PP), polystyrene (PS), ethylene-vinyl acetate (EVA), and polyamide (PA). The filters obtained were examined under a stereomicroscope to identify potential plastic particles. The total number of meso- and microplastic particles obtained for each granulometric fraction and for the whole sample was calculated by combining particles initially separated during raw sample inspection, manually recovered during sieving, and subsequently extracted through density separation.

Quality assurance and contamination control

To minimize airborne and/or cross-contamination during sampling and laboratory processing, materials in direct contact with the sample were preferentially made of metal, glass, or wood. Sediments were air-dried at room temperature and covered with aluminum foil to reduce exposure to airborne particles. All materials were thoroughly rinsed with distilled water and inspected before use. Both the distilled water and the NaCl solution used throughout the procedures were pre-filtered through $0.45 \mu\text{m}$ filters. To monitor and prevent cross-contamination during analytical procedures, Petri dishes containing distilled water and $0.45 \mu\text{m}$ MCE filters were exposed in the working area and examined under a stereomicroscope at the end of each day.

Classification of plastics

Macroplastics (25-1000 mm) were counted, weighed, and classified based on size, color, and presumed source. The classification followed the Ocean Conservancy survey, which categorizes plastic litter into the following groups: (1) most commonly found items, (2) fishing-related gear, (3) packaging materials, (4) personal hygiene products, and (5) other miscellaneous waste. Plastics smaller than 25 mm were classified based on three criteria: (1) size, following the GESAMP (2019) classification into mesoplastics (5-25 mm) and MPs ($<5 \text{ mm}$); (2) shape, including fibers, fragments, pellets, microbeads, sponges, and foam; and (3) color, categorized as white, yellow, gray, transparent, blue, black, red, green, multicolored, or other color (Frias et al., 2018). The quantity of macro-, meso-, and microplastics recovered from the sample was reported as both total items collected and items per kilogram of dry sediment (items/kg). Item concentrations were calculated by dividing the number of particles recovered by the dry mass of the processed sample. As the composite sample analyzed in this study

corresponded to 1 kg of dry material, the reported values in items/kg were numerically equivalent to the total number of items recovered.

Polymer identification

Approximately 12% of the recovered plastic particles from the first stage (mesoplastics and MPs), and 21 potentially plastic particles recovered after density separation (Second phase) were selected for Raman spectroscopy analysis, a non-destructive technique widely employed for polymer identification (Araujo et al., 2018; Jin et al., 2022). Particle selection aimed to represent the variability of the samples based on size, shape, color, and morphology, ensuring the inclusion of representative particles from the different categories identified. Raman spectra were obtained using a Bruker SENTERRA Confocal Raman Microscope (Ettlingen, Germany), equipped with a 20× Olympus objective (NA = 0.40) and an Andor CCD detector with thermoelectric cooling, operated at -66 °C. Laser excitation was performed at 532 nm or 785 nm, with acquisition parameters optimized according to the sensitivity of each sample. The most frequently used settings included an exposure of 5 mW for 3 seconds with the 532 nm laser and 25 mW for 3 seconds with the 785 nm laser. In all cases, five accumulations were taken to enhance the signal-to-noise ratio. The resulting spectra were compared with published reference spectra available in the literature to support polymer identification (Nava et al., 2021). Raman spectra were processed and analyzed using Spectragryph optical spectroscopy software (F. Menges, Version 1.2.16.1, 2022; <http://www.effemm2.de/spectragryph/>).

RESULTS AND DISCUSSION

Macroplastics

Field sampling yielded 110 macroplastic (Figure 2). According to the classification of plastic litter types (Figure 2A), most recovered items corresponded to common plastics associated with urban and recreational activities (67%), followed by fishing-related materials (18%) and other miscellaneous waste (13%), whereas packaging materials represented the smallest proportion (2%). This distribution indicates the predominance of anthropogenic activities related to tourism and coastal use. Regarding the most frequently recovered objects (Figure 2B), bottle caps (35%), cigarette butts (28%), and plastic wrappers (16%) represented the dominant items, while bags (8%), straws (6%), single-use plastic cups (3%), spoons (3%), and containers (1%) occurred in lower proportions. Approximately 72% of the recovered litter was associated with food and beverage consumption and packaging, emphasizing the contribution of single-use products to plastic accumulation on urban beaches. Similar patterns have been reported for highly frequented coastal environments, where recreational activities constitute an important source of plastic inputs (Parker, 2020). According to GESAMP (2019), food and beverage packaging accounts for approximately 36% of global plastic production.

The packaging industry is projected to remain the largest consumer of plastics, with global production volumes expected to rise from approximately 39,9 million tons in 1990 to 236,3 million tons by 2050. Nevertheless, adopting a 15% reduction target by 2040 could help mitigate this upward trend, with plastic consumption potentially declining by 2050, principally if a growing share of packaging materials is effectively recycled (Dokl et al., 2024). The presence of bottle

caps, plastic wrappers, bags, and straws indicates a strong influence from the consumption of single-use plastic products, reflecting the combined impacts of tourism and inadequate waste management in urban environments. Similar patterns of plastic litter accumulation have been reported on beaches in Nueva Cádiz, Spain (Ciufegni et al., 2025), the Mediterranean region of Africa, Tunisia (Baccar Chaabane et al., 2024), and Brazil (Andrades et al., 2020; De Ramos et al., 2021).

The high proportion of cigarette butts (28%), which has also been reported in other studies (Araújo et al., 2022; Dantas et al., 2025), is a concerning finding, as these residues not only contribute MPs through their filters but also release toxic substances into the environment. Previous research has demonstrated that cigarette butts can leach nicotine, heavy metals, and other harmful compounds into seawater, negatively impacting environmental quality and coastal biota (Acarer Arat, 2024). The persistent occurrence of cigarette butts along Boa Viagem Beach suggests persistent inputs associated with recreational beach use.

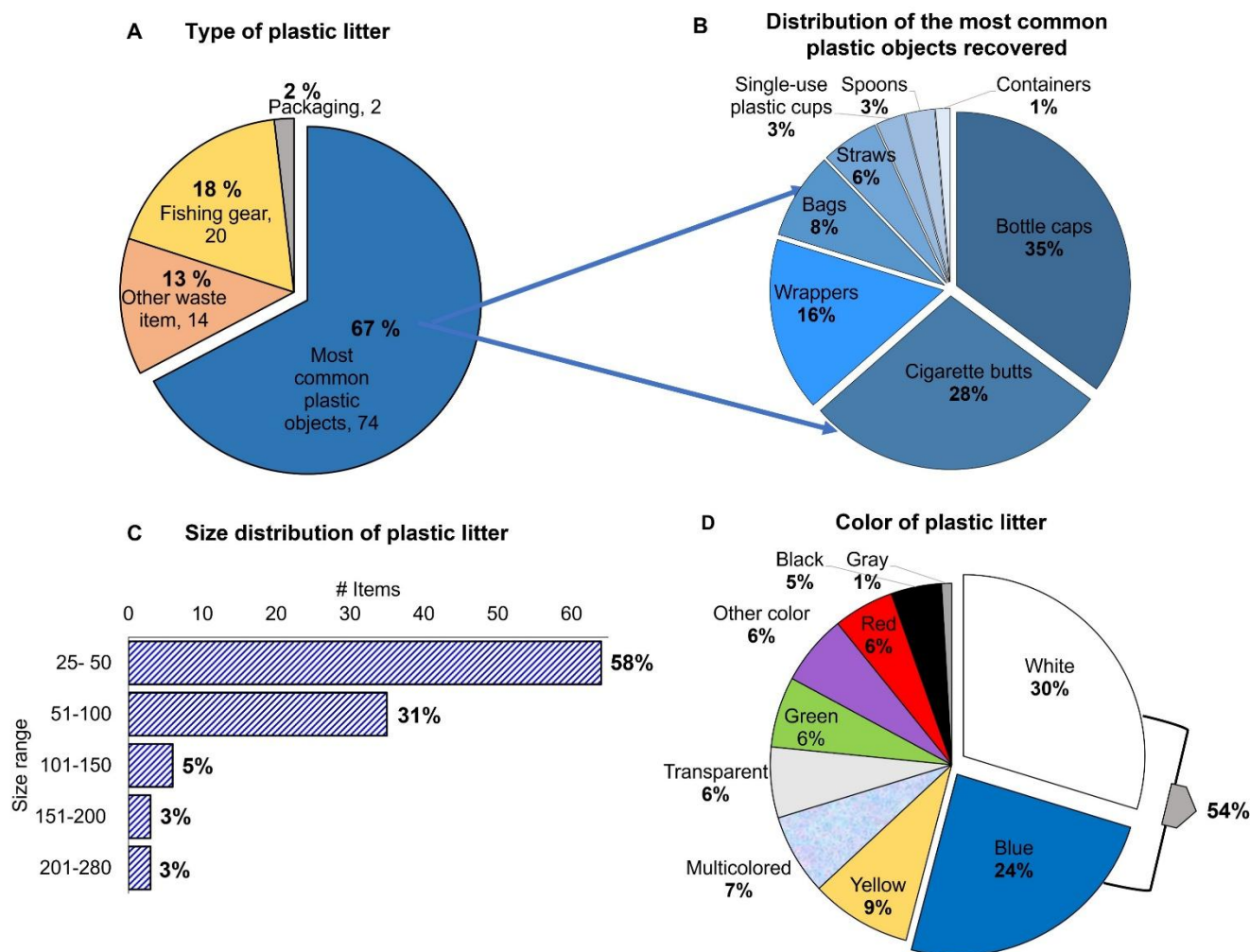


Figure 2. Characterization of plastic litter (macroplastics) from Boa Viagem Beach: (A) Plastic litter types, (B) Common items recovered, (C) size range, and (D) color distribution.

Additionally, the recovery of fishing-related plastic litter (18%) indicates that pollution is also influenced by local economic activities, both small and large-scale (Garcés Ordóñez, 2022). The concentration of plastic litter along the high-tide line and near tourist access points reflects the influence of tidal deposition and beach morphodynamics in this erosive sector, where the discontinuous beachrock barrier and high recreational use enhance retention and fragmentation. Marine currents and wind can redistribute these materials, favoring their accumulation in localized sections of the beach (GESAMP, 2019; Gamboa et al., 2025a).

Macroplastics recovered from the sample ranged from 25 to 280 mm in size. The most frequent size class corresponded to items between 25 and 50 mm (58%), followed by the 51-100 mm range (31%), whereas plastic litter larger than 100 mm occurred at considerably lower proportions (Figure 3C). This size distribution suggests that fragmentation of larger plastic items may be an ongoing process on the beach, likely driven by environmental factors such as UV radiation, wave action, wind, and abrasion with sand, which promote the mechanical and chemical degradation of macroplastics into smaller particles (Gallo et al., 2018; Öborn et al., 2022).

Color analysis revealed a predominance of white and blue (54%, Figure 3D), consistent with other studies and indicative of the degradation of foamed and colored consumer plastics (Cesarini et al., 2022). The color and size patterns observed here, together with the dominance of packaging materials, highlight the central role of urban consumption patterns and recreational activities as the main drivers of coastal plastic pollution on Boa Viagem Beach.

Mesoplastics and MPs recovered in the first phase (by sieving)

From the sieving process, a total of 422 plastic particles (422 items/kg dry sediment) were recovered, of which 56% corresponded to mesoplastics (237 items; 5-25 mm) and 44% to MPs (185 items; <5 mm). Most particles were classified as fragments of various colors and white foam pieces or spheres (Figure 3). Of the 185 MPs recovered, 37 were identified as primary MPs (pellets). The coexistence of fragments and primary pellets on Boa Viagem Beach has been previously documented (Costa et al., 2010; Pinheiro et al., 2019), showing patterns consistent with those observed in this study. The higher proportion of mesoplastics suggests that fragmentation of larger litter is an active process, continuously supplying smaller size fractions in this coastal environment.

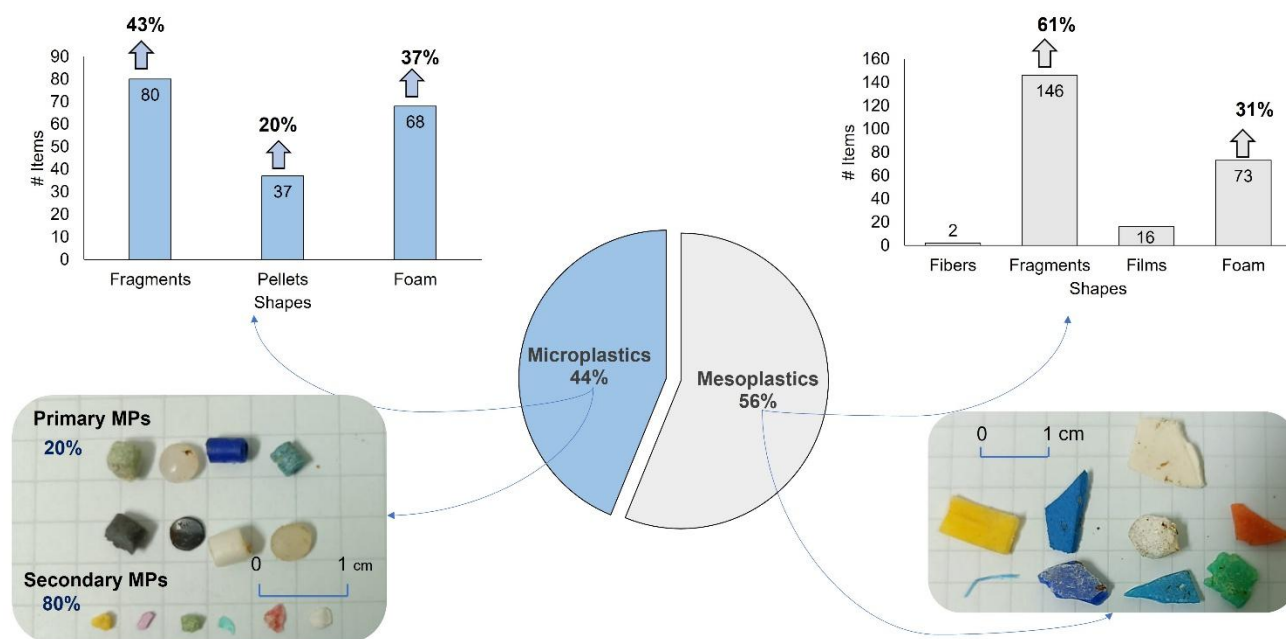


Figure 3. Distribution and characterization of mesoplastics and MPs according to shape.

In 2010, Costa et al. documented the presence of virgin plastic pellets (90 cylindrical, oval, or flattened particles), likely originating from long-distance marine transport, due to the absence of nearby industrial sources to Boa Viagem Beach. They also reported 2661 secondary plastic fragments of various colors (white, red, green, blue, and pink), predominantly irregular hard-plastic pieces formed through photodegradation and mechanical abrasion in the marine environment. Nearly a decade later, Pinheiro et al. (2019) recorded a predominance of blue fragments (49,7%) and a very low occurrence of pellets (only three items). Their spatial analysis showed that smaller particles (<1 mm) were more abundant in protected zones behind rocky formations (60,1%), whereas larger fragments predominated in wave-exposed sectors (75,9%).

For comparative purposes, the MPs abundance obtained during the first phase was expressed relative to the mass of the composite sediment sample (185 items/kg of sediment). This value was lower than those reported for Chancay (306 items/kg), Carpayo (479 items/kg), and Asia (260 items/kg) beaches in Peru (Zarate & Iannacone, 2021), but higher than that reported for San Mateo Beach (12,5 items/kg) in Ecuador (Zambrano Tigua & Pardo Reyes, 2024). Such variability among sites across the Pacific and Atlantic coasts reflects differences in local hydrodynamic conditions, beach morphology, and proximity to pollution sources (Jamšek et al., 2024). Regarding color distribution, white, blue, green, and transparent particles were the dominant categories for both mesoplastics and MPs (Figure 4), which is consistent with previous observations reported for Boa Viagem Beach (Costa et al., 2010; Pinheiro et al., 2019).

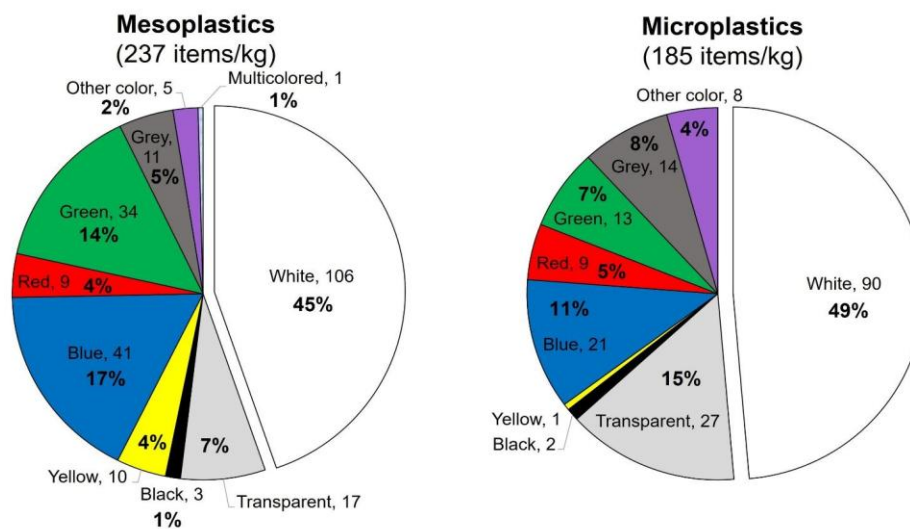


Figure 4. Percentage distribution of colors in mesoplastics (237 items/kg) and microplastics (185 items/kg) recovered from a 1 kg composite sediment sample collected from Boa Viagem Beach sediments, Brazil.

To determine the polymeric composition, 50 particles (~12%), including mesoplastics as well as secondary and primary MPs, were analyzed. As shown in Figure 5, foam spheres (classified as mesofoam or microfoam) were identified as polystyrene (PS). Considering the predominance of foam particles in the recovered assemblage, PS appeared as one of the predominant polymers among the analyzed particles. Mesofibers were composed of PP and PE. Analysis of fragments revealed that most were made of PP (10 mesofragments and 7 microfragments) and PE (7 mesofragments and 2 microfragments). Polymer identification of the selected primary MPs (pellets) indicated the presence of PE and PP. Representative Raman spectra obtained during the analysis are shown in Figure 6.

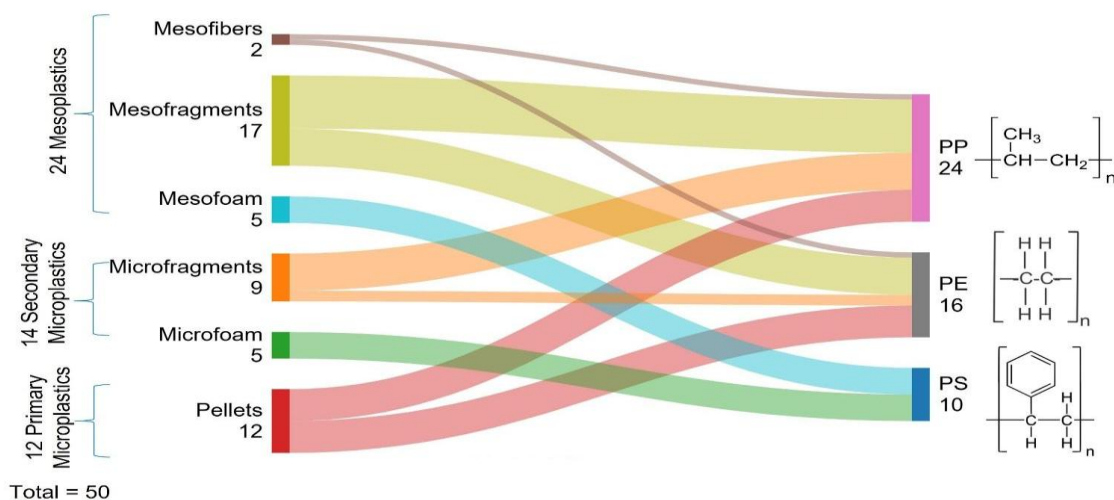


Figure 5. Polymer composition of 50 selected plastic particles (11.85% of the total particles recovered) from Boa Viagem Beach (Recife, Brazil) analyzed by confocal Raman spectroscopy.

The prevalence of PS, PP, and PE reflects the dominance of packaging and foam-derived materials, already observed in the larger plastic size fractions discussed previously. These low-density polymers are easily transported and reworked by wave and tidal processes. This pattern is consistent with global production data for 2024, which identifies PE (high or low-density) as the most produced polymer (26%), followed by PP (19%), and PS (5.1%) (Plastics Europe, 2025). Similar polymeric compositions have been reported on other urban beaches influenced by recreational and commercial activities (Gamboa et al., 2025a,b; Garcés Ordóñez, 2022; García-Varens et al., 2025; Pelegrini et al., 2024).

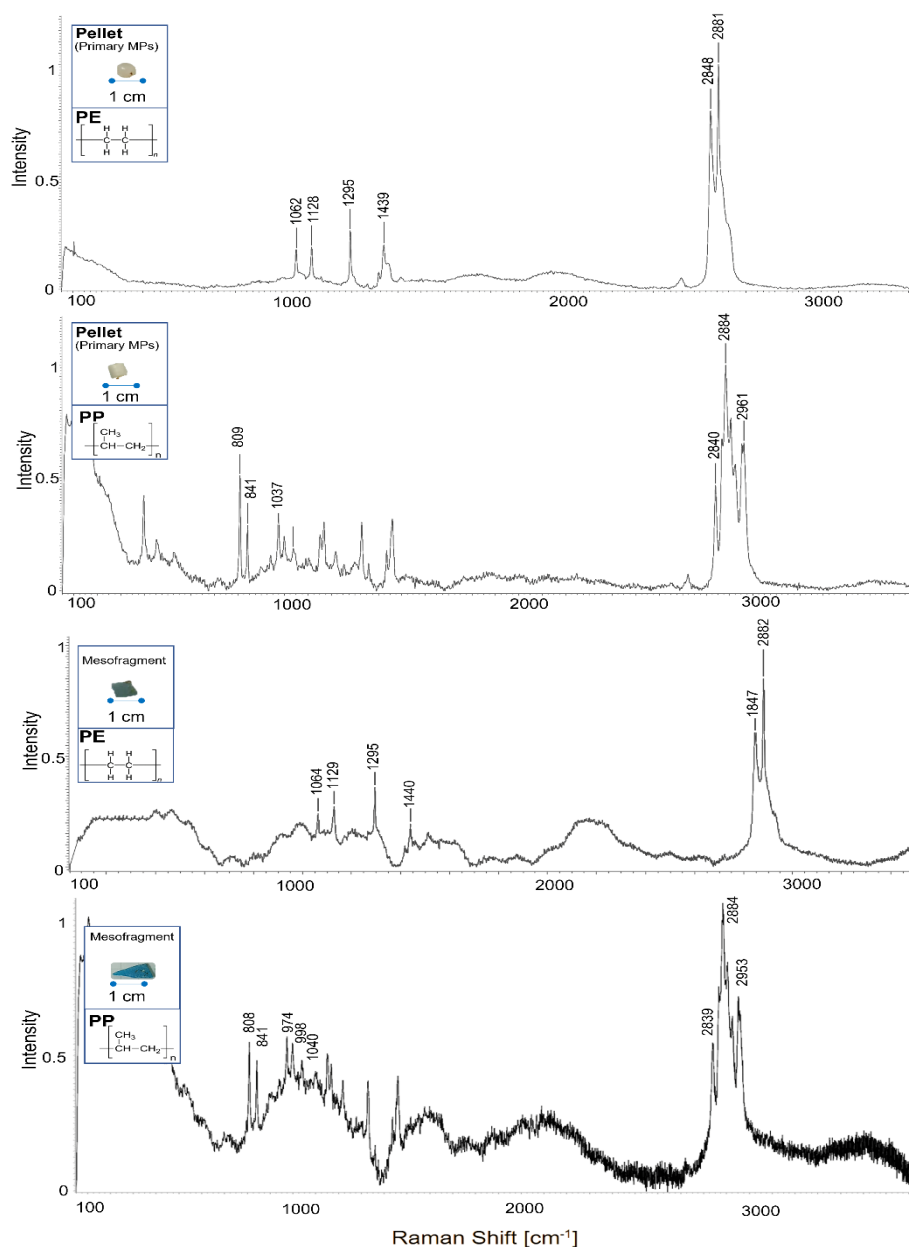


Figure 6. Examples of Raman spectra from plastic particles (meso- and microplastics) collected at Boa Viagem Beach (Recife, Brazil), used for polymer identification.

Plastic particles recovered during the second phase (by density separation)

The granulometric analysis based on sieved sediment fractions revealed a predominance of particles within the 1.00-0.25 mm range (F3), corresponding predominantly to medium-sized sand fractions according to the mesh-based Wentworth classification adopted in this study and representing 68% of the total sediment mass. A total of 49 potential plastic particles retained on the filters were recovered following density separation of all five granulometric fractions (Figure 7). Of the 49 potentially plastic particles recovered after density separation, a subset of 21 particles was subjected to Raman spectroscopy analysis. Polymer identification was successfully achieved for five particles (23.81% of the analyzed particles; Figure 7), including two foam particles (green and white) identified as PS and three blue fragments identified as PP. Initial spectra from several additional particles suggested polymeric characteristics; however, reliable identification was limited by fluorescence effects and particle alteration during analysis.

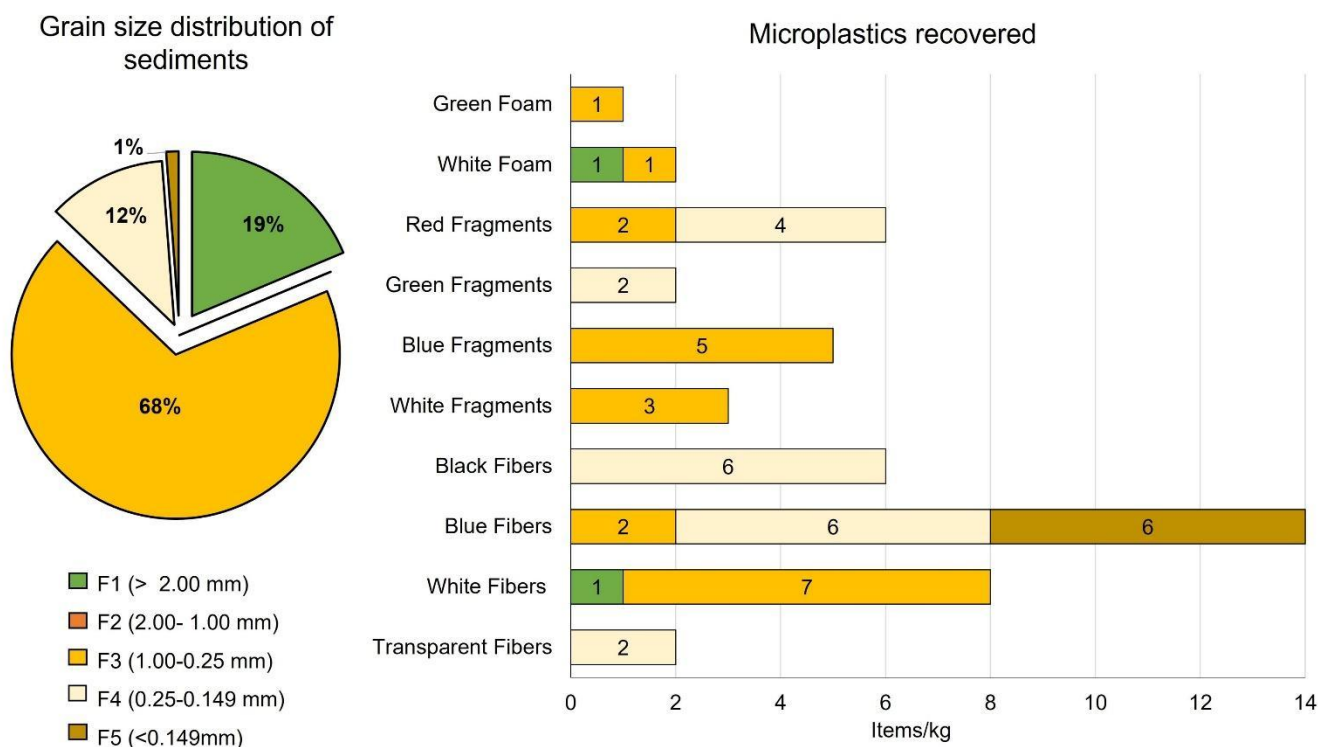


Figure 7. Grain size distribution of sediments and characterization of MPs recovered from surface sediments after filtration (second phase).

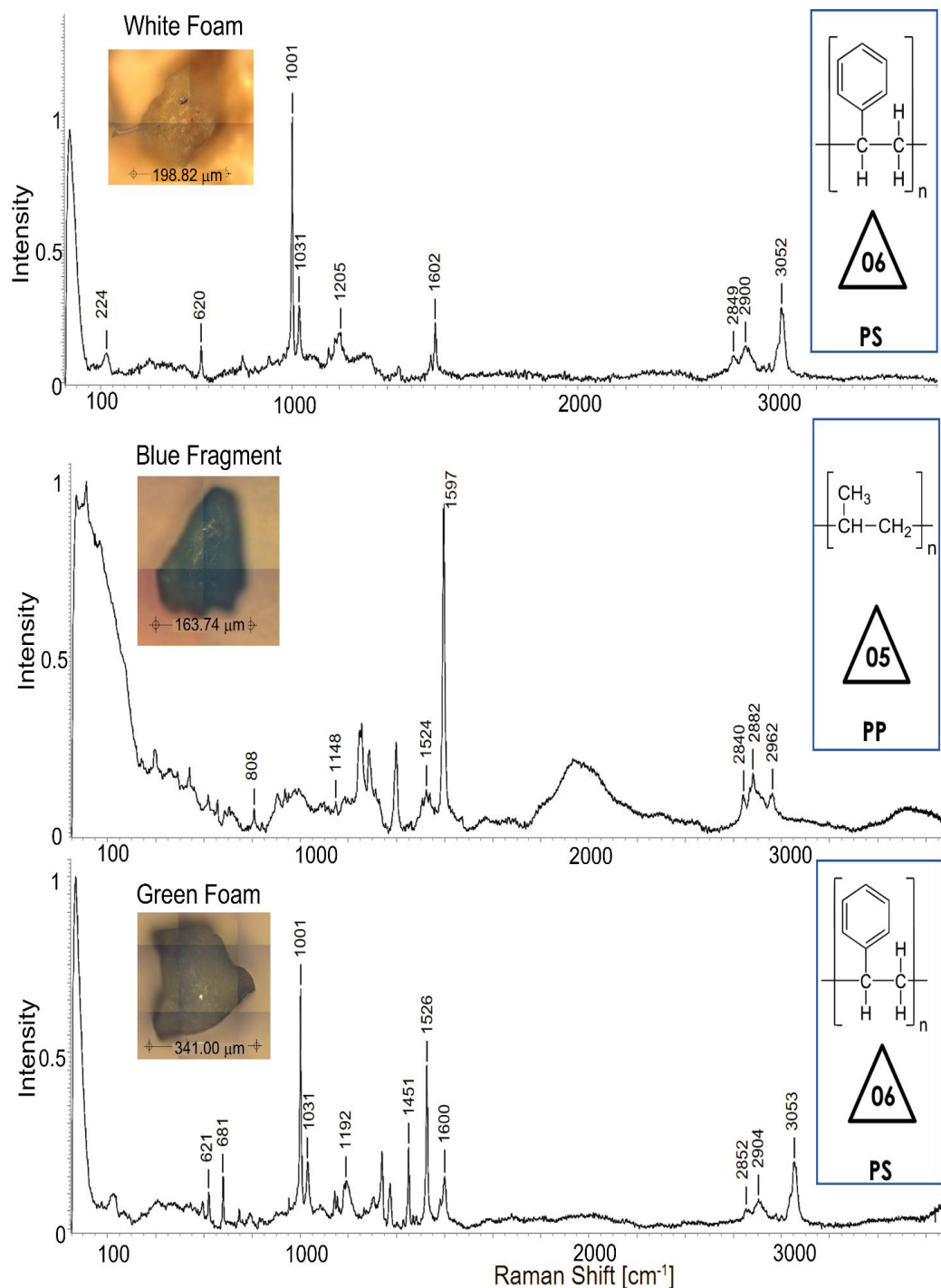


Figure 8. Raman spectra of MPs recovered in the filters after removal of organic matter and resuspension with NaCl.

The reduced spectral resolution observed in some particles may reflect the effects of prolonged environmental exposure, suggesting degradation processes such as oxidation, photodegradation, or biofouling that can modify the optical and chemical properties of plastics (Shi et al., 2024). Figure 8 shows representative Raman spectra of MPs recovered during this phase. The analyzed MPs ranged from 160 to 350 μm in size, emphasizing the occurrence of small plastic particles that, through continued environmental weathering, may further fragment into even smaller particles with greater environmental mobility and bioavailability. The characteristic Raman bands corresponding to each identified polymer are summarized in Table 1.

Table 1. Reference Raman wavenumber assignments for polymer identification.

Raman shift (cm^{-1})	Vibrational Mode Assignment	Associated Polymer
1063	C-C stretching	PE (HDPE/LDPE)
1128	C-C stretching	
1295	CH_2 twisting (or torque)	
1439	CH_2 deformation	
2848	Symmetric CH_2 stretching	
2881	Asymmetric CH_2 stretching	
808	CH_2 rocking	PP
841		
1153	C-C stretching	
2884	Symmetric CH_2 stretching	
2953	Asymmetric CH_2 stretching	
620	Out-of-plane deformation of aromatic ring	PS
1002	Symmetric ring breathing vibration (aromatic ring)	
1601	C=C stretching (aromatic ring)	
2853	Aliphatic symmetric C-H stretching	
2903	Aliphatic C-H stretching	
3054	Aromatic C-H stretching	

CONCLUSIONS

This study provides an integrated size-based characterization of plastics stranded along the high-tide line of a high-energy sector of Boa Viagem Beach (Recife, Brazil), encompassing macro-, meso-, and microplastics. A total of 110 macroplastics were recorded, with the assemblage dominated by materials commonly associated with urban and recreational activities, while fishing-related and other maritime sources contributed to a lesser extent. In addition, 237 mesoplastics and 185 microplastics (including 37 pellets) were recovered during sieving, whereas density separation enabled the recovery of an additional 49 potential plastic particles. Meso- and microplastic were predominantly composed of fragments and foam.

Packaging-related plastics, particularly polystyrene foams, together with polyethylene and polypropylene fragments, were consistently observed across different size classes, reflecting the predominance of consumer-derived materials within the stranded litter assemblage. The occurrence of pellets together with secondary plastic particles further highlights the presence of multiple pathways and forms of plastic contamination within the study area. The coexistence of different plastic size fractions and polymer types within a single coastal sector highlights the complexity of plastic contamination in urban coastal environments.

Although the study was based on a localized sampling design and does not represent the entire beach system, the findings provide baseline information regarding plastic size distribution and polymer occurrence within the sampled sector, supporting future monitoring efforts in erosive urban beach environments. The scope of this article did not include evaluating relationships between sediment grain size and mesoplastic/microplastic abundance; however, this represents an important aspect to be addressed in future studies incorporating broader spatial and temporal replication and extraction protocols based on sieving to enable further inferences regarding such relationships.

Future studies should incorporate spatial and temporal replication to improve understanding of the variability of plastic contamination along Boa Viagem Beach. Complementary analyses addressing ecological interactions, transport processes, and exposure pathways would also contribute to a broader understanding of plastic pollution dynamics in tropical urban coastal environments. Additionally, the information generated here may support discussions related to waste management and mitigation strategies in coastal areas.

ACKNOWLEDGEMENTS

The authors would like to express our sincere gratitude to the Federal University of Santa Maria (UFSM) for the logistical support provided throughout the development of this research. We also thank the FINEP for funding the acquisition and maintenance of the Raman microscope. In addition, we acknowledge the Coordination for the Improvement of Higher Education Personnel (CAPES) for the financial support provided through master's scholarships (PDPG No. 23081.027481/2023-48), doctoral scholarships (PDPG No. 88887.831904/2023-00), and the Visiting Professor in Brazil Program (Academic Solidarity Scholarships, PDPG-SOLIDARIEDADE No. 88887.910945/2023-00). The convergence of these resources significantly contributed to the effective execution of this study.

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BIODATA

Adriana Carolina Gamboa

Es Licenciada en Química de la Universidad Central de Venezuela y Doctora en Ciencias Marinas de la Universidad de Oriente. Actualmente es Profesora Visitante en la Universidad Federal de Goiás, Brasil. Entre 2023 y 2026 realizó actividades como Profesora Visitante en la Universidad Federal de Santa Maria, Frederico Westphalen, Rio Grande do Sul, Brasil. También se desempeña como Profesora en la Universidad Politécnica Territorial del Oeste de Sucre “Clodosbaldo Russián” en Venezuela.

Entre sus publicaciones más relevantes de los últimos cinco años se encuentran:

- Reategui, K., Jardim, L., & Gamboa, A. (2026). Phenanthrene sorption in expanded polystyrene microplastics and environmental aging effects: A Venezuelan Caribbean beaches case study. *Chemosphere*, 398, 144881. <https://doi.org/10.1016/j.chemosphere.2026.144881>
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Sailer Santos dos Santos

Es Doctor en Química y actualmente se desempeña como Profesor Asociado en la Universidad Federal de Santa Maria, ubicada en Santa Maria, Rio Grande do Sul, Brasil. Entre sus publicaciones científicas más relevantes de los últimos cinco años se encuentran:

- Menin, J., Cechin, C. N., Burrow, R. A., Iglesias, B. A., de Freitas Daudt, N., Ledesma, G. N., Cargnelutti, R., Santos dos Santos, S., Schulz Lang, E., & Tirloni, B. (2026). Solar-driven hydrogen production by a modified titania matrix with Pd complexes as co-catalysts. *Journal of Molecular Structure*, 143645. <https://doi.org/10.1016/j.molstruc.2025.143645>
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Andressa Maiara de Almeida Machado

Es Magíster en Ciencias y Tecnología Ambiental, título obtenido en la Universidad Federal de Santa Maria, ubicada en Frederico Westphalen, Rio Grande do Sul, Brasil. Actualmente, se desempeña como profesora de Ciencias en la Educación Fundamental II en el CEPAN - Centro Educacional Padre Anchieta, Santo Augusto, Rio Grande do Sul, Brasil. Su publicación más relevante es:

- De Almeida Machado, A. M., & Marques da Costa, G. (2023). Estágio curricular supervisionado e a importância no processo de formação docente. *Revista Insignare Scientia*, 6(2), 361–379. <https://doi.org/10.36661/2595-4520.2023v6n2.13583>

Kauane Andressa Flach

Es Magíster en Ciencia y Tecnología Ambiental por la Universidad Federal de Santa Maria ubicada en la ciudad de Santa Maria, Rio Grande do Sul, Brasil, y actualmente cursa el Doctorado en Ingeniería Civil y Ambiental en la misma institución.

Entre sus publicaciones más relevantes de los últimos cinco años se encuentran:

- Bones, U. A., Da Rosa, G. M., Flach, K. A., Carissimi, E., & Silvestri, S. (2025). Global alert on virulence and antimicrobial resistance in *Escherichia coli*: A review. *International Journal of Environmental Studies*, 82, 1–24. <https://doi.org/10.1080/00207233.2025.2506270>
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Genesio Mario da Rosa

Es Doctor en Ingeniería Agrícola y actualmente se desempeña como Profesor Titular en la Universidad Federal de Santa Maria en Frederico Westphalen, Rio Grande do Sul, Brasil, donde desarrolla actividades de docencia e investigación vinculadas al área de Ciencia y Tecnología Ambiental.

Últimas publicaciones:

- Gamboa, A. C., Pinto, C., Gutiérrez, G., Casalins, A., Carvajal, M. V., Rojas Ramírez, R. E., Oliveros, N., Villarroel, I. & da Rosa, G. M. (2025). Assessing plastic contamination on a Caribbean Beach: evidence from eastern Venezuela. *Regional Studies in Marine Science*, 104360. <https://doi.org/10.1016/j.rsma.2025.104360>
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Fábio Marcelo Breunig

Obtuvo el título de Licenciado en Geografía en la Universidad Federal de Santa Maria (UFSM) en 2006, y los títulos de Maestría y Doctorado en Sensoriamiento Remoto en el Instituto Nacional de Investigaciones Espaciales de Brasil (INPE) en 2008 y 2011, respectivamente. Entre 2011 y 2023 se desempeñó como profesor en la Universidad Federal de Santa Maria y, desde 2023, es profesor en la Universidad Federal de Paraná.

Tres de sus publicaciones recientes:

- Mosig, C., Vajna-Jehle, J., Mahecha, M. D., Cheng, Y., Hartmann, H., Montero, D., ... & Rivas-Torres, G. (2026). deadtrees. earth—An open-access and interactive database for centimeter-scale aerial imagery to uncover global tree mortality dynamics. Remote Sensing of Environment, 332, 115027. <https://doi.org/10.1016/j.rse.2025.115027>
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