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# Microplastics on the surface of marine waters of the coast of Santa Catarina (Brazil): identification by stereomicroscope and FTIR-ATR spectrophotometer

## Microplásticos na superfície das águas marinhas da costa de Santa Catarina (Brasil): identificação por estereomicroscópio e Espectrofotômetro FTIR-ATR

*Elisangela Silva Lopes Ricardo*[1], *Überson Boaretto Rossa*[1], *Amarildo Otávio Martins*[2], *Eduardo Augusto Werneck Ribeiro*[1], *Costantino Vischetti*[3], *Cristiano Casucci*[3], *Gianluca Brunetti*[3], *Arianna De Bernardi*[3], *Enrica Marini*[3], *Francesca Tagliabue*[3]

## ABSTRACT

The oceans are one of the final destinations for the vast majority of plastic waste; in this sense, particles smaller than 5 mm, classified as microplastics (MPs), represent an environmental challenge with global impact on several ecosystems. The work evaluated the presence of MPs in marine waters off the northern coast of Santa Catarina (Brazil), addressing sampling procedures, opening, characterization, and polymer identification. A low-cost equipment developed with easily accessible materials was tested in the sampling, showing excellent results in terms of buoyancy, stability, and mechanical strength. The concentration of MPs obtained in the study was 0.01 MPs per $m^3$. The particles found were analyzed by stereomicroscopy and classified according to morphological aspects in relation to shape into fragments 58,00%, films 25,00%, and lines 17,00%, and regarding the aspect related to color, blue was predominant. The characterization and polymeric identification was performed by Fourier transform infrared spectroscopy coupled to the total attenuated reflectance module (FTIR-ATR). The types of polymers identified were: polyethylene 33,33%; polypropylene 25,00%; butadiene-styrene copolymer 25,00%, and cellulose 16,66%. The work contributed to the evaluation of an area not yet studied in relation to the presence of MPs in marine waters, while at the same time described in detail the methodologies for analyzing microplastics proposed in the specialized literature.

**Keywords:** polymers; water; waste; methodology; monitoring.

## RESUMO

Os oceanos são um dos destinos finais da grande maioria dos resíduos plásticos; nesse sentido as partículas menores que 5 mm, classificadas como microplásticos, representam um desafio ambiental com impacto global em diversos ecossistemas. O trabalho avaliou a presença de microplásticos em águas marinhas do litoral norte de Santa Catarina (Brasil), abordando os procedimentos de amostragem, abertura, caracterização e identificação dos polímeros. Um equipamento de baixo custo desenvolvido com materiais de fácil acesso foi utilizado na amostragem, apresentando excelentes resultados em termos de flutuabilidade, estabilidade e resistência mecânica. A concentração de microplásticos obtida no estudo foi de 0,01 MP por $m^3$. As partículas encontradas foram analisadas por estereomicroscopia e classificadas quanto aos aspectos morfológicos, com relação ao formato, em fragmentos 58,00%, filmes 25,00% e linhas 17,00%, e, quanto ao aspecto relacionado à cor, o azul foi predominante. A caracterização e identificação polimérica envolvendo os grupos funcionais foi realizada por espectroscopia de infravermelho com transformada de Fourier acoplada ao módulo de reflectância atenuada total (FTIR-ATR), e os tipos de polímeros identificados foram: polietileno 33,33%, polipropileno 25,00%, copolímero butadieno-estireno 25,00% e celulose 16,66%. O trabalho realizado contribuiu para a avaliação de uma área ainda não estudada com relação à presença de microplásticos em águas marinhas, ao mesmo tempo que descreveu detalhadamente as metodologias de análise de microplásticos propostas na literatura especializada.

**Palavras-chave:** polímeros; águas; resíduos; metodologia; monitoramento.

[1]Instituto Federal Catarinense – Araquari (SC), Brazil.

[2]Universidade Federal de Santa Catarina – Blumenau (SC), Brazil.

[3]Marche Polytechnic University – Ancona, Marche, Italy.

Correspondence author: Überson Boaretto Rossa – Instituto Federal Catarinense Campus Araquari – Rodovia BR 280, km 27, nº 5200, Caixa Postal 21 – Colégio Agrícola – CEP 89245-000 – Araquari (SC), Brazil. E-mail: uberson.rossa@ifc.edu.br

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## Introduction

Microplastics (MPs) represent a major environmental challenge of global impact due to their wide dispersion and potential threats to various ecosystems and are even considered a potential geological marker in the Anthropocene era (Olivatto et al., 2018). The most commonly used definition of the term microplastic describes them as synthetic organic polymers measuring less than 5mm resulting from degradation processes of larger plastic waste or directly produced at this size scale (Andrady, 2011; Kershaw et al., 2019).

Global plastics production reached 400.3 million tons in 2022 (Plastics Europe, 2023). The majority of plastic waste ends up in the oceans, accounting for around 80 to 85% of marine litter (Auta et al., 2017). Every year, approximately 8 million tons of plastic waste reach the oceans due to inadequate disposal processes (Jambeck et al., 2015; Napper and Thompson, 2020); the annual amount of plastic arriving from rivers contributes between 1.15 and 2.41 million tons of waste (Lebreton et al., 2017). Estimates suggest that 92% of the 5.25 billion plastic particles on the ocean surface are MPs (Auta et al., 2017).

MPs are residues characterized by their resistance to degradation due to their polymeric properties involving chemical bonds, molar mass, and functional groups. The stable chemical bonds present and the degree of hydrophobicity allow little chemical interaction of plastics and MPs in aqueous media, thus persisting in the environment (Liu et al., 2022). In aquatic environments, MPs promote bioconcentration processes linked to bioaccumulation and biomagnification; impacting fauna and ecological processes across different ecosystems, in addition to posing risks to human health (Sangkham et al., 2022; Haque et al., 2023).

The environmental impacts involving contamination by MPs have been widely documented, demonstrating both environmental and physical toxicological effects caused by the presence of these micropollutants in various ecosystems (Issac and Kandasubramanian, 2021); as well as through the adsorption capacity of potentially toxic substances, amplifying the toxicological potential of micro and macro pollutants (Tong et al., 2023). Regarding human health, recent studies have reported the presence of MPs in placentas of pregnant women and their genotoxic potential in human blood lymphocytes (Çobanoğlu et al., 2021; Ragusa et al., 2021).

Since they were first observed in the 1970s (Carpenter and Smith, 1972), the presence of MPs has been reported in numerous studies involving environmental matrices (Jung et al., 2022; Tian et al., 2023) indicating a growing number of investigations related to this problem worldwide. While extensively studied in Europe, Asia, and North America, Latin America, despite contributing 4% of total plastic production and 8% of total plastic consumption worldwide (Plastics Europe, 2023), has limited publications concerning investigations on MPs presence and impacts (Fernandes et al., 2022). Furthermore, research carried out both in Latin America and other regions lacks standardization involving methods of analysis and classification of MPs (Grillo et al., 2022). Determining the ecological damage caused by MPs and associated chemicals is a key objective of the European Union Marine Strategy Framework Directive (MSFD, 2008).

In Latin America, Brazil stands out as the country that has been developing the most research in the area (Kutralam-Muniasamy et al., 2020), highlighting that although studies carried out in Latin America have mostly focused on marine environments, scientific efforts have been heavily focused on MP contamination in biota samples (41%), followed by sediment/soil (37%), and water (22%) (Fernandes et al. 2022). Regarding studies carried out in Brazil, there is a predominance of research on aquatic matrices and sediments with a focus on marine ecosystems, but with identification mainly through visual inspection (Montagner et al., 2021). However, the lack of knowledge about MPs in terms of polymer types, transport, fate, and impacts highlights the urgent need for further investigation.

Although it is complex to determine the origin of MPs found in coastal environments, studies suggest that rivers are one of the main inputs of plastic pollution into the oceans, especially in countries lacking efficient treatment systems or monitoring (Terzi and Seyhan, 2017; Alam et al., 2019). Densely populated Brazilian urban areas present chronic problems involving the non-existence or incorrect management of solid waste which, added to the impacts involving floods and inadequate wastewater treatments (Sodré et al., 2023), leading to increase contamination of freshwater sources and, consequently, oceans.

Brazil ranked seventh among countries releasing the most plastic into the oceans via rivers, with a total of 3.8,104 million tons per year, according to a study by Meijer et al. (2021). Developing countries like Brazil suffer from inadequate waste treatment system and the lack of monitoring. In 2019, Brazil produced approximately 14 million tons of plastic waste, of which only 4.5% of plastic packaging was recycled, contributing to the release of an unknown fraction into the environment (Pincelli et al., 2021).

In a study carried out by OCEAN CLEANUP on a global scale, analyzing a thousand rivers with the greatest impact on plastic release into the oceans, the state of Santa Catarina (Brazil) has ten rivers with anthropic impact related to MPs (Meijer et al., 2021); the Itajaí Açu river stands out as the most polluting in the state of Santa Catarina, with 641.8 kg/year.

Praia Grande, the focal point of this study, is located north of nine of the ten most polluted rivers in Santa Catarina; located in the city of São Francisco do Sul, the third oldest city in Brazil. Anthropogenic impacts in the region occur due to port activities at São Francisco do Sul and Itapoá. The region is also impacted by large demographic growth, influenced by property speculation and regional tourism along the Santa Catarina coastline. The industrial development of the state, the impacts generated by local rivers that transport micro- and macro-pollutants into the oceans (Pedro and Vieira, 2018; Rech, 2018), and the contribution of coastal marine currents carrying MPs to the beaches (Auta et al., 2017), significantly affect the presence of MPs on the surface of coastal seas in this region. A study on the classification and quantification of debris in the Praia Grande region led to the collection of a total of 137.13 kg of marine debris, with plastic constituting

79% of the total waste collected (Stelmack et al. 2018). However, no work has been carried out to identify the presence of microplastics in surface water in the region.

Considering the problem involving the contribution of rivers to the supply of plastic waste into the oceans and the predominant longitudinal drift current toward the north according to studies carried out by de Castilhos and Gré (2004), which can influence the transport of contaminants, including plastics, this work carried out a qualitative investigation of contamination involving the presence of MPs in marine waters in the Praia Grande region. Additionally, waste characterization of the waste was conducted to contribute to research efforts in the southern region of Brazil and reduce information gaps regarding the occurrence of contamination by MPs in the region. Procedures were carried out to collect and evaluate MPs based on reference protocol methodologies developed by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (Kershaw et al., 2019) as well as the National Oceanic and Atmospheric Administration protocol (Masura et al., 2015). These detailed procedures serve as a valuable contribution to future research endeavors, aiming to address the lack of standardization regarding collection methods, sample processing, and identification, thereby facilitating meaningful comparisons across studies involving MPs.

## Methodology

The sampling procedures, extraction, and characterization methods followed the protocols developed by Kershaw et al. (2019) and Masura et al. (2015), including modifications regarding the procedures for purification samples and density separation according to the new literature available.

### Location and collection of samples in marine waters

Sampling of MPs in marine waters was carried out along the coastline in the northern region of Santa Catarina, in the municipality of São Francisco do Sul, opposite Praia Grande beach, located between Praia da Saudade and Barra do Sul (Figure 1). Praia Grande has a sandy stretch of approximately 26 km, bathed by the Atlantic Ocean and surrounded by a permanent environmental preservation area, linked to the Acaraí State Park (Pedro and Vieira, 2018). Georeferenced points for the collection of MPs samples in marine waters were determined with the aid of a Garmim eTrex Vista HCx Global Positioning System (GPS). The geo-reference coordinate points were respectively: (1) S 26°14'10.6" W 48°29'55.8"; (2) S 26°14'30.4" W 48°30'04.4"; (3) S 26°14'26.1" W 48°30'00.7"; (4) S 26°14'41.7" W 48°30'04.4"; (5) S 26°14'11.1" W 48°29'52.9"; (6) S 26°14'11.8" W 48°29'49.4". Trawling runs were performed by towing a sampler containing a neuston net, attached to the boat with long nautical ropes. A sport fishing boat with a combustion engine propulsion was utilized for towing; during the course, alternations were made in the direction of sampling (Figure 1) to enhance representativeness in relation to the distance from the coast.

During sampling, the boat was conducted toward ocean waters, and the nautical speed was maintained constant at two knots; the collection points were made at a distance of approximately 300 m from the sandy range of Praia Grande, totaling three sampling points at one nautical mile. With the objective of expanding the representative seasonal period, three sampling campaigns were conducted between June and October 2022, with tidal conditions varying from 0.1 to 0.4 m.

The sampling of MPs in water was carried out using a cost-effective neuston net (Figure 2) with a mesh diameter of 300 um, built according to the sampler suggested by Masura et al. (2015); the sampler construction procedure, the materials used, and its operating instructions are described in details by Ricardo et al. (2022). This low-cost equipment exhibited excellent results in ocean waters.

The samples containing aqueous matrices from the 6 georeferenced collection points were transferred in glass jars sealed with metal screw caps, packaged in a thermo-insulated box under ice, and promptly forwarded to the laboratory within few hours. Upon arrival, samples were then stored in a refrigerator at approximately 4°C until analysis. The analyses were carried out in the laboratories at *Instituto Federal de Educação, Ciência e Tecnologia Catarinense* (IFC).

### Control and manipulation of samples

In order to avoid contamination of samples with environmental particles during both collection and laboratory manipulation, several quality control measures were adopted. Glassware was cleaned with detergent, followed by triple rinsing with deionized water (HPLC grade) and ethanol, and dried in a drying oven; the samples were handled using nitrile gloves and cotton lab coat during all the experiments. Procedures were performed in a horizontal laminar flow booth (Lutech brand) to minimize potential airborne particulate contamination. Work surfaces were thoroughly cleaned with 70% ethanol prior to the beginning of the experiments, involving sample processing. Control samples underwent identical opening and preparation conditions; procedural blanks were performed with deionized water samples in parallel with the environmental samples from marine waters. No blanks were taken during field sampling.

### Separation and preparation of samples

The first separation process was done through sieving using stainless steel sieves. Fragments smaller than 5 mm and larger than 0.3 mm were separated by overlapping sieves with 5.6 mm, 1 mm, and 0.3 mm meshes. It is important to point out that since MPs have classification sizes below 5.0 mm, particles retained in the 5.6 mm sieve were removed and analyzed for eventual presence of macro-plastics, while residues retained in the 0.3 mm sieve were transferred to a beaker for the digestion procedure in order to eliminate interfering agents, such as organic matter, and to investigate the presence of MPs. During the sieving steps, naked-eye examination was followed by manipulation with histological forceps, a fundamental step for the separation and collection of suspected MPs particles.

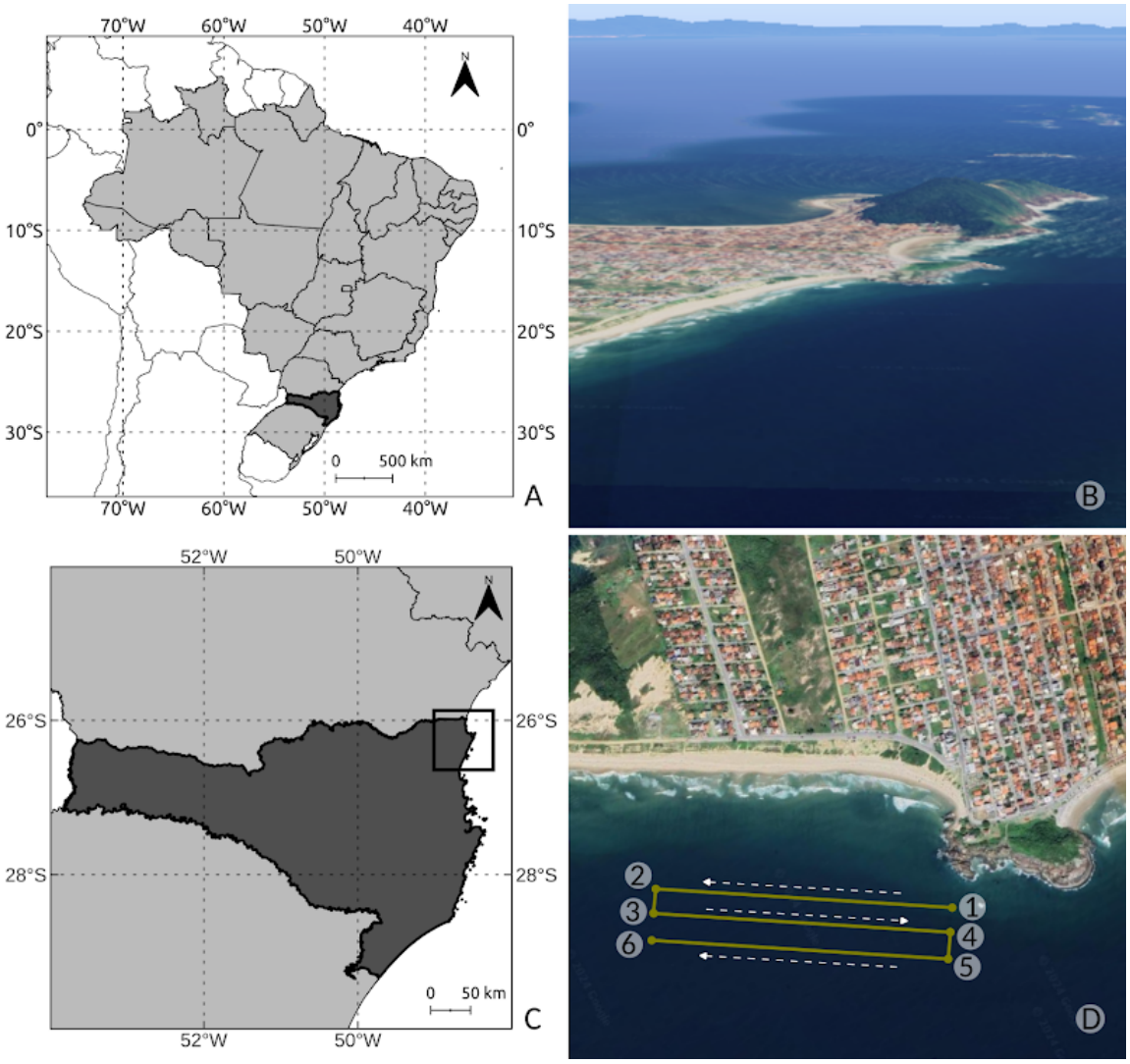


**Figure 1 – Sampling points in marine waters on the northern coast of Santa Catarina (Brazil) (A, C) close to Praia Grande with the respective coordinates of the navigation path (B, D).**
Satellite imagery data source: Google Earth with author modification.

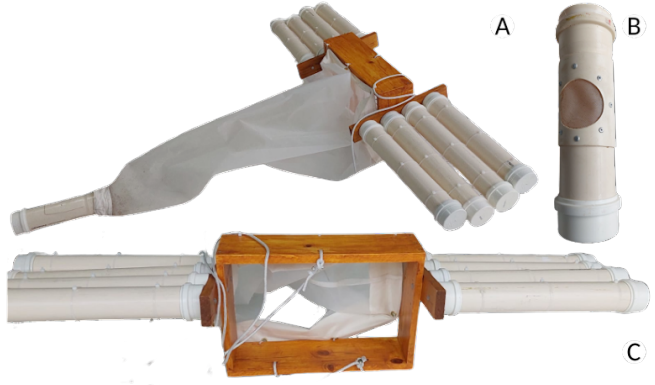


**Figure 2 – Details of the sampler and the sample collector cup attached to the mesh of neuston net (A, B, C).**
Source: Ricardo et al. (2022).

Further steps aimed to separate MPs from natural interfering agents such as sediment and biological tissues. The samples processing was carried out according to the protocols developed by Kershaw et al. (2019) as well as by Masura et al. (2015), with modifications suggested by relevant scientific work (Imhof et al., 2012; Dehaut et al., 2016; Zobkov and Esiukova, 2017).

The samples were first digested in an alkaline medium, using a potassium hydroxide (KOH) solution at a concentration of 10% (m/v), in a proportion of 40 ml of alkaline solution for each 0.2 gram of sample. The solutions were incubated for 24 hours at a temperature of 60°C in a hot water bath. After digestion in a basic medium, the solutions were then neutralized to a pH value close to 7.0 with a 30% (v/v) hydrochloric acid (HCl) solution, verified with an Alfakit model at-355 pH-meter.

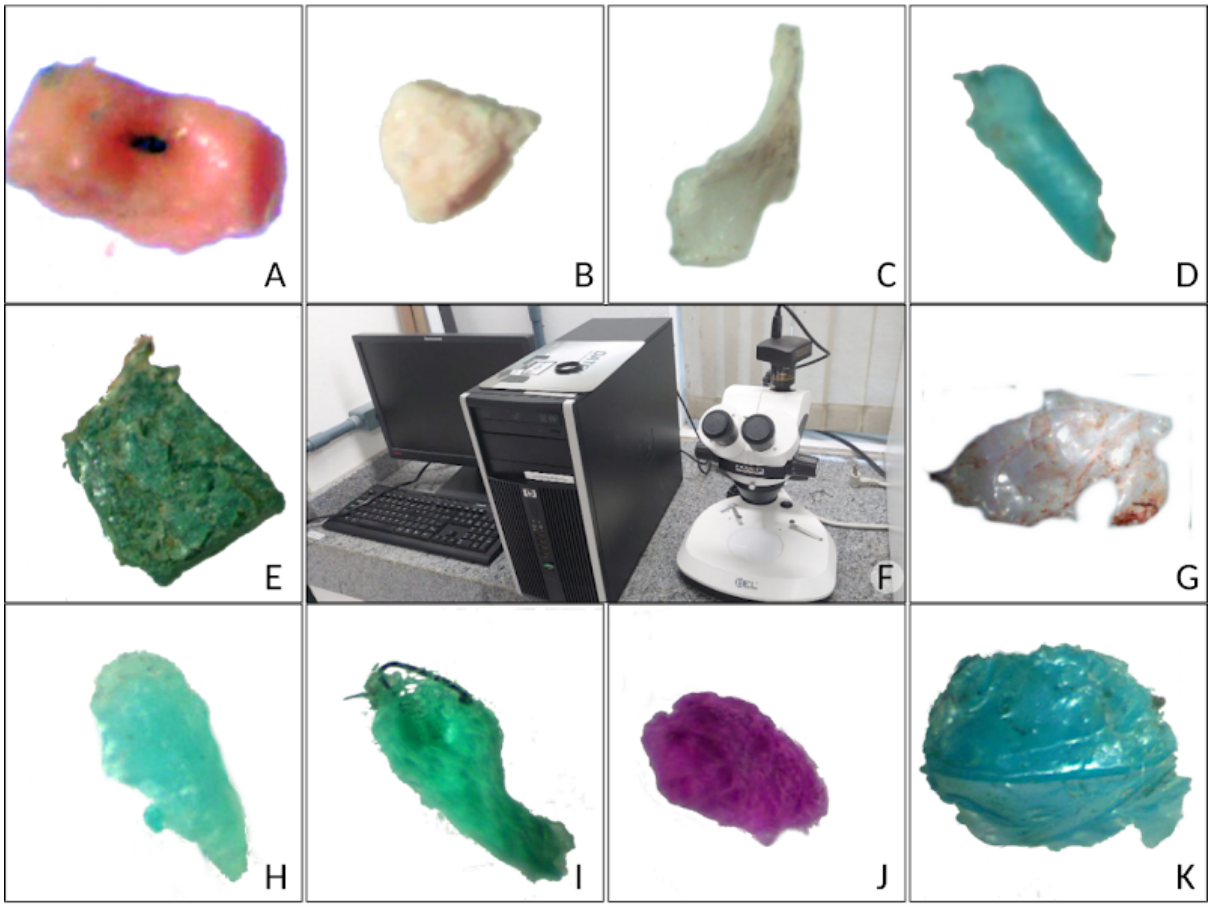


**Figure 3 – Stereomicroscope coupled to the camera and software for image processing (F) and microplastic fragments observed at 40x magnification. (A) 0.8 mm polyethylene; (B) 0.2 mm of styrene; (C) 1.2 mm polyethylene; (D) 1.4 mm polyethylene; (E) 1.9 mm polyethylene; (G) 4.3 mm polyethylene; (H) 1.4 mm polyethylene; (I) 1.8 mm of cellulose; (J) 1.7 mm of cellulose; (K) 3.0 mm polyethylene.**

Subsequently, a density separation procedure was used to separate the polymers from the residual sediment that withstood alkaline digestion. The separation process is directly related to the polymer density, which may vary depending on the plastic manufacturing process, the chemical composition of the microplastic and the polymeric molecular structure, as well as the substances and organisms adsorbed to the microplastic from the environmental matrix. To achieve an efficient separation of MPs from the environmental matrix, a solution with densities greater than 1.4 g/cm$^3$ has been recommended (Quinn, 2017). For this purpose, a solution of zinc chloride ($ZnCl_2$) was used after neutralization, with a density ranging from 1.6 to 1.7 g/cm$^3$ (Imhof et al., 2012; Zobkov and Esiukova, 2017). The MPs separation was achieved after 24 hours using a glass funnel filled with $ZnCl_2$; after this period, the polymeric particles were filtered and separated, followed by stereomicroscope visualization.

## Microscopic characterization and morphological classification

Particle identification in terms of shape, size, and color was made using a 40x Bell stereomicroscope (Figure 3) coupled with a digital camera (0.3 MP ¼" color USB 2.0 APTINA CMOS SENSOR). Image treatment was performed using the software provided by the camera manufacturer in parallel with visual analysis. Fragment classification based on morphology encompassed pellets, fibers/lines, films, and foams (Figure 4), taking into account sizes and colors according to the GESAMP protocol recommendations (Kershaw et al., 2019). During the MPs separation process from marine waters, it is important to visually separate plastics from other materials present in the environmental matrix, as this step is mandatory for data collection prior to possible spectroscopic confirmation (Kershaw et al., 2019).

## Characterization by FTIR-ATR Spectroscopy

An Agilent Cary 630 FTIR-ATR spectrophotometer was used for sample characterization. The Agilent FTIR spectrophotometer featured an Attenuated Total Reflection (ATR) module equipped with a single reflection zinc selenide (ZnSe) prism and a sampling press (Catoggio, 2022).

Microplastic samples were placed directly in the ATR analysis module with the aid of fine-tipped histological tweezers. The fragments found were identified according to the different polymeric molecular

structures and to polymer/copolymer types within a wavelength range of 650–4,000 $cm^{-1}$. The functional groups present in the polymer of interest absorb part of the electromagnetic radiation in relation to the molecular structure; the transmittance intensity is relative to the functional group characteristic of each MP. Operational parameters of the equipment were set to 32 sample scans, 32 background scans, and resolution of 8.

After spectral scanning, MP identification was performed using both the specific manufacturer library and polymers spectral data available from literature (Silverstein et al., 2006; Paiva et al., 2010). According to the databases used, the MPs were identified with precision and accuracy ranged between 80 and 100% in comparison with standard spectra.

## Results

During the three sampling campaigns, 900 $m^3$ of marine waters were evaluated. In the first campaign, no polymer particles were found; in the second campaign, particles of MPs were obtained, and in the third campaign, a mesoplastic particle along with 11 MPs were obtained, totaling a concentration of 0.013 MPs per cubic meter. No plastic particles were observed in the controls used during sample processing in the laboratory.

The twelve plastic particles presented heterogeneous physical characteristics in terms of colors, types, and sizes. One of the twelve particles evaluated was classified as mesoplastic, measuring 23.8 mm, and eleven particles classified as microplastic, ranging in size between 0.2 and 4.3 mm.

The mandatory visual examination of samples during the data collection process before possible spectroscopic confirmation was meticulous; During the visual identification process, particles were classified according to their morphology related to shape (fragments, pellets, fibers/lines, films, and foams) as well as their observed color. In a total of 12 particles classified according to morphology related to shape, seven fragments, three films, and two lines were classified; in terms of color, there were four blue, two white, two green, two translucent, one orange, and one magenta (Figure 4).

The twelve plastic particles were further analyzed using FTIR-ATR; and the definition of the particles was obtained regarding the type of polymers of four polyethylene, three polypropylene, three butadiene-styrene copolymers, and two cellulose (Figure 5).

The relative FTIR-ATR transmittance spectra are shown in Figure 6. Polypropylene samples (Figure 6A) showed characteristic signatures occurring approximately at 2,950 and 2,880 $cm^{-1}$ wavelengths that were associated to the asymmetric stretches of C-H bonds relative to methylenic and ethylenic functional groups; the symmetrical stretches of C-H bonds in methylenic and ethylenic functional groups were evident around 2,930 and 2,820 $cm^{-1}$ respectively. Angular deformations related to C-H of the ethyl and methylenic functional groups occurred at wavelengths of 1,370 and 1,450 $cm^{-1}$, respectively (Silverstein et al., 2006; Paiva et al., 2010).

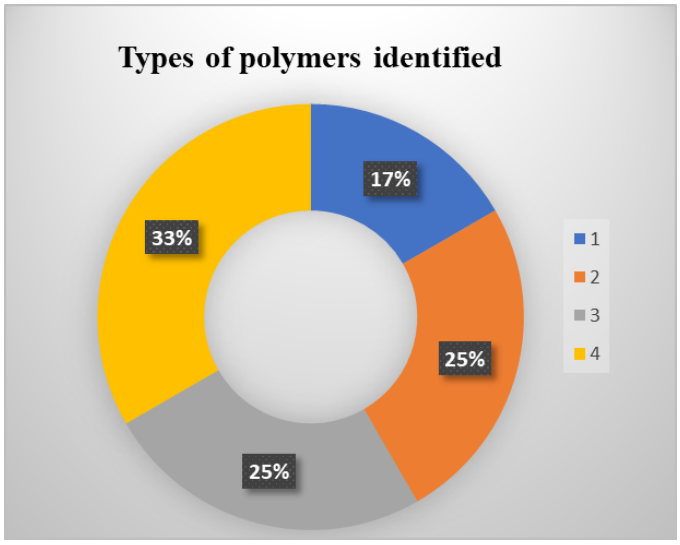


**Figure 5 – The types of polymers identified: 1- cellulose 16,66%; 2- polypropylene 25%; 3-butadiene-styrene copolymer 25%, and 4- polyethylene 33,33%.**

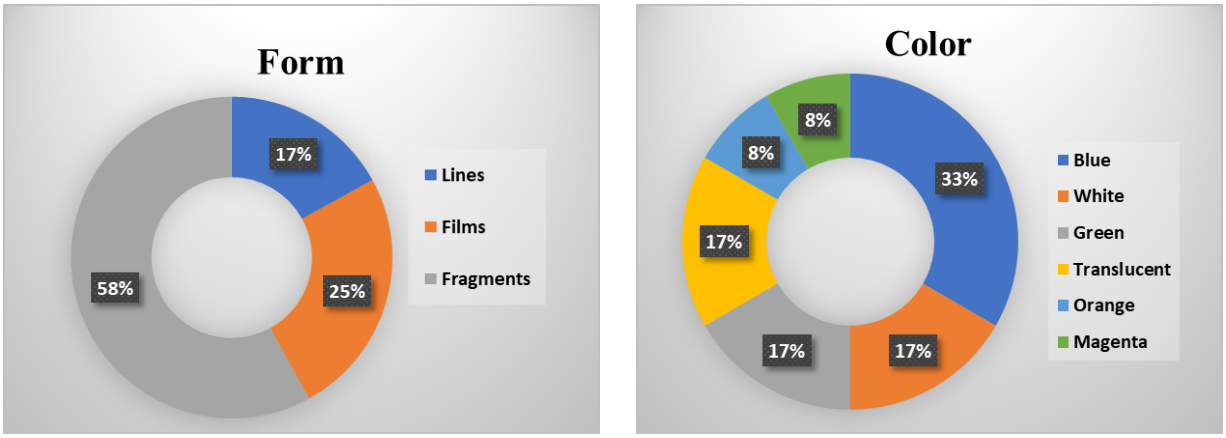


**Figure 4 – Left: Morphological aspects related to particle shape. Right: Morphological aspects related to particle color.**

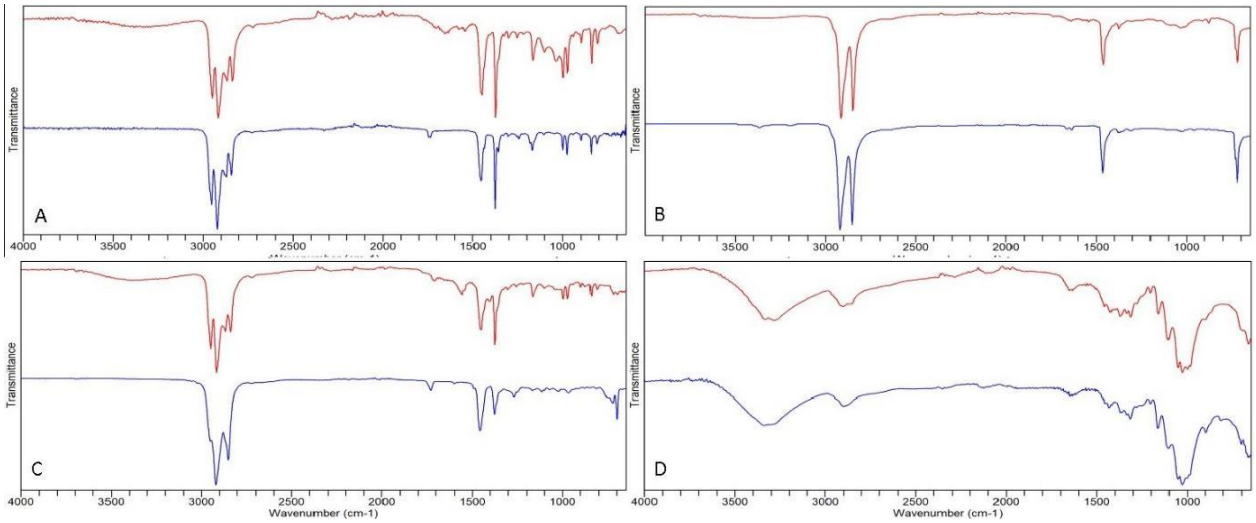


**Figure 6 – FTIR-ATR transmittance spectra of selected samples with spectral scanning from 650 to 4,000 cm$^{-1}$: (A) polypropylene polymer; (B) polyethylene polymer; (C) styrene-butadiene; and (D) cellulose polymer.**

Similar behavior was noted in the polyethylene samples (Figure 6B), with characteristic signals detected at approximately 2,900 and 2,850 cm$^{-1}$, relative to symmetrical and asymmetrical stretches of C-H bonds, and around 1,450 cm$^{-1}$, indicative of C-H angular deformation (Silverstein et al., 2006; Paiva et al., 2010).

Characteristic signatures of a styrene-butadiene copolymer were observed for the spectral scan of the sample reported in Figure 6C; features of styrene-butadiene polymers functional groups were observed in regions close to 2,950 and 2,850 cm$^{-1}$ and were associable to the C-H stretches of saturated carbons of the styrene benzene ring, and to the C-H stretches of unsaturated butadiene carbons. Additionally, characteristic stretches of the C=C bonds of both styrene and butadiene were detected in the region between 1,400 to 1,500 cm$^{-1}$. It should be noted that the physical characteristics of copolymers similar to rubber, such as tenacity and hardness, might be affected when samples are pressed with a histological forceps.

The spectrum of the sample in Figure 6D was attributed to a cellulose fiber, exhibiting characteristic signatures of cellulose functional groups in the mid-infrared region; it manifested both intense signals with a maximum at 3,480 cm$^{-1}$ relative to the stretching of the O-H bond, and high-intensity signals at 2,918 and 2,850 cm$^{-1}$ due to the stretching of the C-H bonds.

## Discussion

The concentration of MPs obtained in the study was lower compared to other studies carried out in Brazil focusing on marine waters (Olivatto et al., 2019; Castro et al., 2020), as well as in studies involving freshwaters (Ferraz et al., 2021; da Costa et al., 2023). However, as reported in the review by Orona-Navar et al. (2022), studies across Latin America display highly variable results, making comparisons between studies complex. This variation may be related to factors such as climatic differences during sampling, sampling protocols, quantification, location, among others.

Sampling was carried out using a low-cost equipment constructed using light and commercially accessible materials according to the NOAA reference model (Masura et al., 2015); it was easy to handle and provided efficient results in terms of buoyancy, stability, and mechanical strength without requiring any further structural modifications during boat campaigns.

Samplers with trawling type meshes have limitations in relation to the small size and small amount of water sampled and lack of selectivity to secondary MPs as fibers (Liu et al., 2019); however, the sampler presented excellent results considering the volume of water sampled in only three campaigns. MPs found in the marine waters sampled included polypropylene, polyethylene, cellulose, and styrene-butadiene copolymer.

Physicochemical characteristics were visually verified both by naked eye and by stereomicroscopy. The retrieved polymer particles displayed heterogeneous physical characteristics in terms of colors, types, and sizes, ranging from approximately 0.20 to 23.8 mm, confirming the presence of both MPs and mesoplastics. The wide diversity of forms demonstrated by MPs occurs mainly due to the physicochemical degradation processes. Consequently, most studies involving MPs classification, such as the ones by Frias and Nash (2019) and Edo et al. (2020), adopt classification criteria based on physicochemical characteristics.

Particles sized between 0.2 and 0.5 mm were observed with the aid of the stereomicroscope to minimize the risk of misidentification, as suggested for particles smaller than 500 µm by Renner et al. (2018) and Lusher (2020a).

Visual characterization involving color and line shape was decisive for the identification of an artificial cellulose fiber, although distinguishing between viscose or cellulose acetate remained uncertain. In fact, previous studies have confirmed the difficulty of differentiating artificial cellulosic fibers (Rayon/Viscose) solely through microscopy (Comnea-Stancu et al.,

2017), underscoring the importance of using both the visualization stage and the spectroscopic identification to minimize false positives.

However, it should be noted that, regarding MPs' shape, the presence and use of several classification parameters in the worldwide literature demonstrated the absence of an objective approach during particles classification and revealed inconsistencies that could reduce the comparability between studies, limiting speculations about possible sources.

According to studies by Shim et al. (2017), due to the typically irregular MPs surface, FTIR-ATR spectra generally offer better quality compared to the spectra obtained in reflectance mode, but are inferior to those obtained in transmission mode, although smaller MP particles are more easily detectable by FTIR-ATR when compared to transmission mode. However, the main disadvantage of FTIR-ATR is the need for surface contact between the sample and the ATR crystal, requiring appropriate technical preparation by the operator during sample handling.

The disadvantages cited by Shim et al. (2017) were observed in the present study, however the identification was very rapid because there was no need for prior samples preparation, streamlining the analysis of various particles. The successful use of the FTIR technique for polymer identification of MPs fragments in environmental matrices, as mentioned by Käppler et al. (2016), Mecozzi et al. (2016), and Yang et al. (2023), could contribute to improve the monitoring of the origin and distribution of these micropollutants in several matrices.

The interpretation of spectra from particles collected from the environment poses challenges due to degradation, aging, or particles coating with biofilms, as reported by Morgado et al. (2021).

## Conclusions

The morphological classification of MPs was successfully performed in conjunction with spectroscopic identification of constituent polymers; polypropylene, polyethylene, cellulose, and butadiene-styrene copolymer were the materials identified. The MP sampling technique used here for the marine water matrix showed both stability and ease of handling, so its use is recommended. The FTIR-ATR technique provided efficient results in the identification of particles, displaying accuracy, agility as well as ease of sample preparation.

Further research is needed in the region at different times of the year involving quantitative studies that contribute to monitoring the presence and distribution of MPs as well as the development of appropriate methodologies for different environmental matrices with the aim of achieving a good level of standardization and validation of MPs' analyses. Standardization is essential to enable comparison between studies and during long-term monitoring of marine waters. Obtaining new knowledge about different fractions in terms of size, morphology, distribution, and types of polymers could thus contribute to a clear assessment of the dynamics and impacts in various environmental compartments; Furthermore, it could lead to more effective prevention measures and improve environmental management policies. This work contributed to the assessment of a marine area not yet studied regarding the presence of MPs and detailed the MP analysis methodologies, integrating the protocols developed by GESAMP and NOAA with other important related modifications to purification techniques in order to achieve excellent results.

## Authors' contributions

RICARDO, E.S.L.: conceptualization, data curation, formal analysis, investigation, writing – original draft, writing – review & editing. ROSSA, Ü.B.: conceptualization, data curation, supervision, validation, formal analysis, investigation, methodology, writing – original draft. MARTINS, A.O.: data curation, formal analysis, funding, acquisition, investigation, methodology, project administration. RIBEIRO, E.A.W.: data curation, formal analysis, funding, acquisition, investigation, methodology, project administration, resources. VISCHETTI, C.: conceptualization, data curation, formal analysis, funding, acquisition, investigation, methodology, writing – original draft, writing – review & editing. CASUCCI, C.: conceptualization, software, supervision, validation, visualization, writing – original draft, writing – review & editing. BRUNETTI, G.: conceptualization, data curation, formal analysis, funding, acquisition, investigation, methodology, writing – original draft, writing – review & editing. DE BERNARDI, A.: conceptualization, data curation, formal analysis, funding, acquisition, investigation, methodology. MARINI, E.: conceptualization, data curation, formal analysis, methodology. TAGLIABUE, F.: conceptualization, data curation, formal analysis, methodology, writing – original draft.

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