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First report of plastic biomedia contamination in Brazilian beaches – evidence from the Paraná coast

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ABSTRACT

We present the first report of plastic biomedia contamination on Brazilian beaches based on evidence collected from 14 beaches of the Paraná state coastline (southern Brazil). Plastic biomedia, also called biocarriers, are small, perforated plastic pieces used worldwide in wastewater treatment plants (WWTP) that apply the Moving Bed Biofilm Reactor (MBBR) process. Accidental release of these particles into the environment adds to Ocean's long-term plastic pollution problem. A high amount of plastic biomedia presence in the coastal areas of Paraná was first noticed by a community member, who found 411 plastic particles on a beach located in Pontal do Paraná, bringing this issue to our attention. In this study, plastic biomedia was retrieved from drift line alongshore transects (0.3 to 1 km long) and cross-shore transects (5 m wide) from the water line to the backshore zone. A total of 749 items were collected from 11 of the 14 sampled beaches, including the Mel and Superagui Islands nature reserves. The decreasing trend in plastic biomedia abundance with the increase in distance of the PEC southern outlet suggests that these particles probably originate from a WWTP in the Paranaguá Estuarine Complex (PEC). Once in the water, these floating plastic particles that followed the suspended sediment transport pattern were exported to coastal waters and were transported by longshore currents. Highlighting the potential role of the PEC as a substantial vector for marine debris to the Paraná coastline. The most likely source of this novel plastic contaminant to the Brazilian coastline are WWTP with MBBR systems. Therefore, stakeholders need to discuss and establish a reporting system so that plastic biomedia spillovers or losses are reported, and its dispersal in the environment is reduced.

Keywords: Novel contaminant, Plastic debris, Beach, Wastewater treatment plants, South Brazil

Plastic biomedia, also known as filter media, are small, perforated plastic pieces (polyethylene [PE] or high-density polyethylene [HDPE]) used as bacterial biofilm carriers to improve the wastewater treatment process, invented in Norway in the 1980s (Ødegarrd et al., 1994; Ballerini et al., 2022). These plastic particles, also called biocarriers, are applied in the Moving Bed Biofilm Reactor (MBBR) technology, the most used technique in wastewater treatment plants (WWTP) worldwide (Madan et al., 2022). This includes but is not limited to urban, industrial, and aquaculture wastewater treatment (Maurya et al., 2023). Although recognized by their

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improvement in wastewater treatment efficiency, plastic biomedia from WWTP MBBR systems can be accidentally released into the environment (e.g., in WWTP basin to overflows due to heavy rain episodes), and between a few thousand up to several million pieces can be introduced into the environment (Bencivengo et al., 2018). Therefore, plastic biomedia may also represent a potential threat to marine ecosystems, adding to the long-term plastic pollution problem in the Ocean.

Plastic pollution is a global issue. Every year, more than 460 million tons of plastic are produced globally (OECD, 2022), and several plastic items, on the order of 0.13–3.8 million metric tons, are estimated to enter the ocean every year (Zhang et al., 2023). Once in the marine environment, plastic debris tend to rapidly concentrate on coastal areas (Lavers and Bond, 2017). Due to their increased dispersion potential and persistence, plastics in the marine environment threaten marine wildlife and, potentially, humans (Gall and Thompson, 2015). However, to address marine plastic pollution, its sources, sinks, and spatial and temporal distribution trends must be understood, which require long-term datasets with broad spatial coverage. Therefore, the magnitude and sources of plastic entering the ocean remain poorly known (Solutions…, 2023). Recently, citizen science has been applied as a good tool for achieving this, as it involves members of the public and provides information for developing evidence-based policies toward reducing marine plastic pollution (Nelms et al., 2022). The first observation of plastic biomedia on the European coastline was made by a Surfrider Foundation Europe volunteer, which led to the establishment of the citizen science-based European plastic biomedia observation network (Bencivengo et al., 2018).

In Brazil, the implementation of WWTP systems that use MBBR is growing, and the last Brazilian National Water and Sanitation Agency report shows that, in 2017, 19 WWTPs applied this technology (ANA, 2020). So far, to our knowledge, there are no records of accidental environmental inputs nor of the presence of these plastic particles in Brazilian coastal environments. Therefore, this study is the first report of plastic biomedia occurrence on Brazilian sandy beaches (Figure S1, Supplementary Material), where these particles were found in 11 beaches from the coastal areas of the Paraná state (south Brazil) (Figure 1). As the first European plastic biomedia observation, a Pontal do Paraná community member brought this issue to our attention during a university outreach activity on June 26, 2023. This community member observed the presence of small, rounded plastic circles (16 mm in diameter) (Figure 2A) during a leisure walk at the beach, close to the DNOS channel (~1.2 km), and collected them using other plastic debris (i.e., plastic bottles) available at the beach. At the lab, we identified the material as plastic biomedia and counted 411 items. It is worth noting that, despite different marine debris studies being conducted in this area (Krelling et al., 2017, 2023; Bettim et al., 2021; Nunes et al., 2021; Mesquita, 2022), the presence of plastic biomedia, classified as mesoplastic (plastic items in the 5 – 25 mm size fraction), was not reported before. Therefore, we decided to investigate this issue further to elucidate the possible sources of these particles on the Paraná coastline.

The Paraná coastline (25.70° S, 48.47° W), southern Brazil, lies between two estuarine outlets of the Paranaguá Estuarine Complex (PEC) and Guaratuba Bay, being the second smallest oceanic coast (~90 km) in the country (Figure 1). The ocean-facing beaches are mainly composed of fine, well-sorted sands, classified as wave-dominated, with a significant tidal influence inside and at the estuary outlets, where large ebb-tidal-deltas influence beach sand transport and sedimentary budget (Angulo et al., 2016, 2020). The mean significant wave height in the 18 m isobath is 1.6 m, with a maximum of 4.5 m (Angulo et al., 2016) and a predominant SSE-S wave direction (Nemes and Marone, 2013). At the PEC southern outlet, ebb currents are stronger than flood currents at both the surface and the bottom, with a seaward balance of the sediment transport (Noernberg et al., 2007; Mayerle et al., 2015). At the coastline, sediment transport is controlled by longshore currents that flow to the north (Figure 1) (Noernberg et al., 2007).

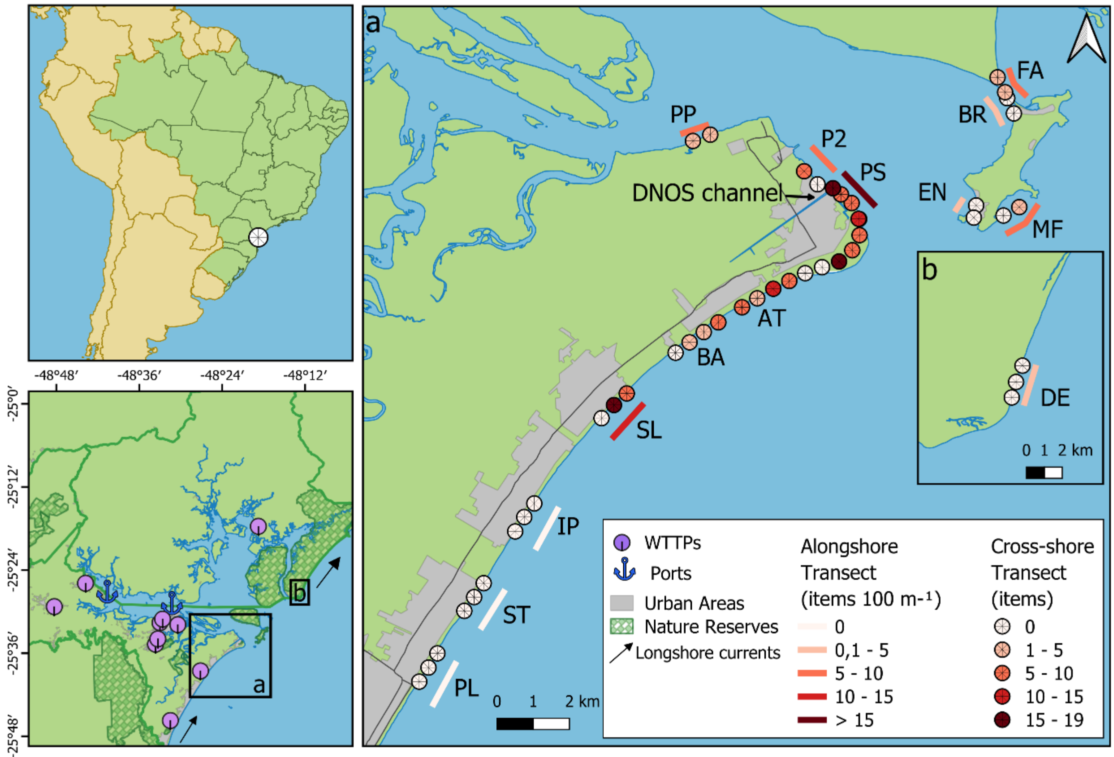

Figure 1. Map of the Paraná's coastline where plastic biomedia was found in July/August of 2023, in Pontal do Paraná and Mel Island (a), and Superagui Island (b). The number of plastic biomedia per linear 100 m (items 100 m−1) obtained in the alongshore transects (colored lines), and average abundance (items) in the cross-shore transects plastic (colored circles). The bottom left panel shows the location and extent of Paraná's coastline nature reserves (hashed green areas) and urban areas (gray areas), the location of WTTPs (purple circle) and ports (anchor symbol), and the direction of the longshore currents (based on Noernberg et al. (2006) - arrows).

The state of Paraná has several Nature Reserves, including the Guaraqueçaba Environmental Protection Area (APA de Guaraqueçaba), which includes the Superagui National Park (PARNA do Superagui) and the Mel Island State Park and Ecological Station (PE/ESEC Mel Island) (Grise et al., 2009). At the Paraná coastline, coastal anthropization has been happening since the 1950s, with the increase of the coastline urban development and recreational beach use during the summer (Angulo et al., 2020). Nowadays, the region houses 301,000 people (IBGE, 2023), developing activities that include fishing, farming, power generation, harbor, tourism, and recreation (Angulo et al., 2020). The region holds two port terminals in Antonina and Paranaguá; the latter is Brazil's second-largest public port (Figure 1). There are 11 WWTPs in the vicinity of the PEC (Figure 1), six of them in Paranaguá, and the other five distributed in each coastal municipality (ANA, 2020; Prefeitura de Antonina, 2020; Prefeitura de Paranaguá, 2021).

Plastic biomedia sampling took place on 14 beaches in the municipalities of Pontal do Paraná, Paranaguá (Mel Island), and Guaraqueçaba (Superagui Island), and sampling campaigns occurred in July and August 2023 (Table 1, Figure 1). Sampling locations were selected considering their distance to the PEC outlet, which is a potential source of marine litter (Possatto et al., 2015; Krelling et al., 2017; Krelling and Turra, 2019; Bettim et al., 2021). We applied two distinct approaches to retrieve plastic biomedia in the sampled beaches: (i) at least two 5-m wide cross-shore (perpendicular to the water line) transects located between the backshore zone (approximately 1 m seaward of the vegetation line) and the water line and with a minimum distance of 0.5 km apart from each other per beach (N=41) and (ii) 0.3 to 1 km alongshore (parallel to the water line) transects located at the drift line (N=12). These were thoroughly searched and plastic biomedia items were collected (Table 1). The cross-shore transect approach is a commonly applied sampling design in macro debris investigations (e.g., Shoreline Survey Guide of NOAAs Marine Debris Monitoring and Assessment Project) (Burgess et al., 2021), which may be a better approach to understanding the spatial distribution of plastic biomedia, as sampling is less time-consuming, enabling investigating teams to cover large areas. At the same time, we chose to sample the alongshore transects to mimic Ocean Clean Up efforts, which should be more effective for quantifying the total abundance of plastic biomedia and providing an idea of the size of spillover events. Sampling was conducted by at least two scientists who thoroughly examined all stranded debris on the cross-shore transects to ensure the retrieval of any entangled, concealed, or trapped biomedia, and visually inspected the drift line debris, retrieving plastic biomedia on the alongshore transects. All collected biomedia were taken to the lab and quantified. Data for each location is reported as plastic biomedia abundance (items) in the cross-shore transects and the alongshore transects abundance (items) and concentration of biomedia, defined as the number of particles per linear 100 m (items 100 m^{-1}).

Figure 2. Plastic biomedia found in Paraná's coastline (a, b), and the diverse set of environments where these particles were observed: on sandy beaches, drift line together with marine debris (c), by itself on top of the sand (d), with typical mangrove propagule debris (e), interaction with a propagule of *Avicennia schauerianna* (f), on top of a riprap structure (g), and at a Ponta do Poço mangrove forest (h).

Table 1. Plastic biomedia collected from Paraná's beaches. Data on alongshore transects abundance (items), length of the transect (m), and concentration (items 100 m-¹); and cross-shore transects: number of transects (N), and abundance (items).

		Alongshore transect			Cross-shore transect	
ID	**Beach**	**Abundance (items)**	**Length (m)**	**Concentration (items 100 m-¹)**	**N**	**Abundance (items)**
AT	Atami	-	-	-	3	24
BA	Barrancos	-	-	-	4	9
BR	Brasília	6	507	1.18	2	0
DE	Deserta	3	1000	0.3	3	0
EN	Encantadas	2	378	0.53	2	0
FA	Farol	61	749	8.15	2	4
IP	Ipanema	0	1036	0	3	0
MF	Mar de Fora	62	936	6.63	2	2
P2	Pontal 2	26	480	6.04	2	5
PL	Praia de Leste	0	1028	0	3	0
PP	Ponta do Poço	35	564	6.2	2	8
PS	Pontal do Sul	247	456	54.11	10	79
SL	Shangri-lá	148	1080	13.71	3	28
ST	St. Terezinha	0	1033	0	3	0

Table 1 provides plastic biomedia data, which are represented in Figure 1. These particles were present in 11 of the 14 sampled beaches, totaling 749 items (159 in the cross-shore transects and 590 in the alongshore transects). The cross-shore transects data show that no plastic biomedia were found at the three Pontal do Paraná beaches (Praia de Leste, Santa Terezinha, and Ipanema) and at the two estuarine-facing Mel Island beaches (Brasília and Encantadas). Plastic biomedia were also not observed in the alongshore transects at the same Pontal do Paraná beaches but were present at Pontal do Sul (54.1 items 100 m^{-1}), Shangri-lá (13.7 items 100 m^{-1}), Ponta do Poço (6.2 items 100 m^{-1}), and Pontal Dois (N = 6.0 items 100 m^{-1}) beaches. These particles were also present on the ocean-facing Mel Island beaches, Farol (8.1 items 100 m^{-1}), and Mar de Fora (N = 6.6 items 100 m^{-1}). Although not quantified in this work, during the sampling campaigns, plastic biomedia were observed in different coastal environments from the Paraná coastline (Figure 2), such as riprap structures (2g), mangroves (2h), *restinga* vegetation, coastal dunes, and adrift in the seawater.

The fact that plastic biomedia had not been reported in our study area before June 2023, despite previous (Moreira et al., 2016; Bettim et al., 2021; Mesquita, 2022; Krelling et al., 2023; Figure S1) and ongoing marine debris investigations, suggests that its presence in the Paraná coastline and, consequently, environmental input is most likely recent. Our research group performed a marine debris investigation field campaign that sampled Praia de Leste, Shangri-lá, and Pontal do Sul beaches in mid-May 2023, and these particles were not observed on that occasion. Therefore, it is likely that the plastic biomedia input reported in this study is related to a punctual event or a chronic input that started between mid-May (the last field campaign) and mid-June of 2023 (the first observation from the community member). However, additional sampling campaigns are necessary to determine if the plastic biomedia input comes from a single event or is chronic.

These particles' general spatial distribution pattern highlights higher plastic biomedia mean cross-shore transects abundance between the oceanic beaches closer to the PEC southern outlet (Pontal do Sul, Atami, and Shangri-lá) than the other sampled beaches (t-test < 0.000005). Previous investigations suggest that the PEC is a substantial vector for macro marine debris (domestic, sewage, and fisheries-related) to the Pontal do Paraná beaches, especially to the region adjacent to the estuarine southern outlet (Krelling et al., 2017; Krelling and Turra, 2019), and particularly during high precipitation events (>20 mm) (Bettim et al., 2021). Our results now showcase that this is also the case for the plastic biomedia (mesoplastic). Moreover, within the PEC urban, industrial, and/or aquaculture WWTP could represent potential sources for the plastic biomedia. However, it is worth mentioning that the recent (April/May 2023) implementation of the MBBR technology at an urban WWTP located within the PEC and high precipitation events on May 30-31, 2023 (16.3 and 17.0 mm, respectively) and June 13-14, 2023 (35.2 and 20.4 mm, respectively) (Instituto das Águas do Paraná, 2023) favor the hypothesis of a punctual input event derived from a source within the PEC. Also, during sampling campaigns, we observed that these particles were mainly found beached together with typical mangrove forest vegetation debris (Figure 2g), with registers of interaction between plastic biomedia and *Avicennia schaueriana* propagules (Figure 2h). As mangrove forests are mainly located inside the PEC (Noernberg et al., 2006), this reinforces the hypothesis that the plastic biomedia found at the Paraná coastline are derived from a PEC facility, possibly an urban WWTP.

Once in the water, these floating plastic particles would follow the suspended sediment transport pattern, primarily exported from the PEC via its southern outlet and into coastal waters (Mayerle et al., 2015). Our data also show that the last occurrence of these particles occurs at the Shangri-lá beach, which has been pointed out as the southern limit of the PEC influence on large marine debris abundance on the Paraná coastline by a floating debris mathematical model (Krelling et al., 2017). Nevertheless, once plastic biomedia (or any floating debris) reaches coastal waters outside the PEC outlet and tidal range influence, these particles should follow the longshore currents' sediment transport patterns. In the Paraná coastline, wave-driven longshore currents and sediment transport show a predominantly northward direction (Noernberg et al., 2007; Angulo et al., 2020), which explains the fact that plastic biomedia were also present at the oceanic-facing Mel Island (Mar de Fora and Farol) and Superagui (Deserta) beach (Figure 1b). This emphasizes the potential role of the PEC as a marine debris vector, not only for the Pontal do Paraná beaches but also for the northern portion of the Paraná coastline, where important nature reserves are located, such as Mel Island State Park and Ecologic Station and Superagui National Park.

Recent studies have shown that plastic debris densities, particularly macro- and microplastic, in remote beaches (Barnes et al., 2018), including those within marine-protected areas (Nunes et al., 2023a, 2023b) or protected by treaties or agreements, are at alarming levels. As artificial borders are unable to inhibit plastics from entering these areas (Bonanno, 2022) hindering their critical role in conserving marine and coastal biodiversity, landscapes, and resources, knowledge about plastic debris presence, abundance, and distribution is essential (Nunes et al., 2023a). Once in the environment, plastic biomedia may be accidentally ingested by marine species, such as sea turtles, that inhabit these protected areas (Bencivengo et al., 2023), thus contributing to the degradation of ecosystems. However, most studies about plastic pollution in coastal and marine systems focus on macro- and/or microplastics, ignoring the mesoplastic size fraction, resulting in a lack of standardized protocols, knowledge gaps, and policy needs associated with plastic debris size fraction (Shi et al., 2023). Mesoplastic baseline studies are frequently conducted together with microplastic surveys, which involve sampling a small beach area (e.g. Ambrose and Walker, 2023). However, our data shows that, regarding accidental plastic biomedia inputs, this specific type of mesoplastic debris may spread across extensive beach stretches. Thus, the combination of commonly applied macroplastic beach survey sampling strategies, encompassing larger beach areas, provides robust data regarding plastic biomedia abundance and distribution. We propose adopting this approach if similar accidental plastic biomedia inputs occur in other beaches.

In conclusion, this is the first report of plastic biomedia in the Brazilian coastline. Our results suggest that a PEC WWTP is the source of these plastic particles, highlighting the PEC's detrimental role as a marine debris vector to the Paraná coastline. Therefore, it supports the idea that marine debris management requires efforts from local stakeholders across coastal Paraná municipalities (Krelling and Turra, 2019). Given the fact that this novel contaminant is applied to WWTP MBBR systems and its growing trend of implementation, stakeholders, including public and private wastewater treatment users, and environment protection agencies, need to discuss and establish a reporting system in which WWTP users can report any plastic biomedia spillovers or losses into the environment, aiming to reduce dispersal. Additionally, WWTP managing companies should have protocols for identifying and preventing plastic biomedia from entering the environment, as this is widely considered the best solution for the marine plastic pollution problems (Solutions for plastic pollution, 2023, Bencivengo et al., 2023). For the Paraná state, this is of particular importance since its coastline harbors important ecosystems protected by state and federal law, and MBBR technology is planned to be implemented at WWTPs on Pontal do Paraná (SANEPAR, 2023) and Mel Island (Prefeitura de Paranaguá, 2021). The adoption of alternative MBBR biomedia composed of materials other than plastic (Mnyoro et al., 2022) should also be considered by all involved stakeholders. Moreover, although we did not apply citizen science in this study, it highlights the importance of connecting local community members and academia, as citizens are central stakeholders in the development of the United Nations treaty on plastic pollution (Nelms et al., 2022; Oturai et al., 2023).

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AUTHOR CONTRIBUTIONS

R.H.N.: Conceptualization; Investigation; Supervision; Writing – Original Draft.

Y.W.M.; A.A.; C.C.V.N.M.; A.B.T.N.: Investigation; Visualization; Writing – review & editing.

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