PLASTIC PELLETS IN THE SANDY SEDIMENT OF BEACHES ON THE MIDDLE COAST OF RIO GRANDE DO SUL, BRAZIL

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ABSTRACT

Purpose: Pellets are plastic granules used in the industry to manufacture many materials and can be lost to the environment throughout the production chain. This study evaluated the number of pellets on beaches, on the middle coast of the state of Rio Grande do Sul, a region with low urban agglomeration, and few studies on this topic. The quantity found in relation to the distance from the port of Rio Grande was also evaluated.

Method: The collection of sandy sediment occurred in three seasons of the year and, for each beach, quadrants were sampled at the mark of the last high tide.

Results and conclusion: 96.26% of the pellets were collected in spring, 3.74% in autumn, and none in summer. Storm events and large amounts of organic matter may explain the result in spring, while strong winds may have influenced the summer collection. The results found did not show a direct relationship with the distance from the Port, since there was no well-defined distribution pattern.

Research implications: It is essential to map the loss of pellets in the environment, including in sparsely urbanized areas. Pellets can be lost during transport at sea, where currents and winds can carry them to different regions. Therefore, control and management measures for losses of these materials are necessary.

Originality/value: The work is unprecedented and maps pollution by plastic pellets on beaches with little anthropogenic activity in Rio Grande do Sul. The results indicate that is important an integrate coastal management.

Keywords: Microplastic, Sandy Beaches, Pellet Pollution, Beach Pollution, Coastal Management.

RESUMO

Objetivo: Avaliar a quantidade de pellets em praias, no litoral médio do estado do Rio Grande do Sul, região com baixa aglomeração urbana e poucos estudos referentes a esta temática. Também, analisar se a quantidade de pellets encontrada possui relação com a distância do porto de Rio Grande.

Referencial teórico: Os pellets são grânulos de plástico utilizados na indústria para fabricação de diversos materiais e podem ser espalhados no ambiente ao longo de toda a cadeia produtiva.

Método: A coleta de sedimento arenosos ocorreu em três estações do ano e, para cada praia, foram amostrados quadrantes, em triplicata, na marca da última preamar.

Resultado e conclusão: 96,26% dos pellets foram coletados na primavera, 3,74% no outono e nenhum no verão. Eventos de ressaca e grande quantidade de matéria orgânica podem explicar o resultado da primavera, enquanto

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1 INTRODUCTION

Worldwide, the production of plastic materials has increased considerably, producing more than 390 million tons per year worldwide (Statista, 2023). The vast majority of the materials produced originate from virgin plastic granules, also known as pellets, nibs or plastic beads. These small granules have different shapes (spherical, ovoid and cylindrical), colors (clear, white or transparent) and sizes (1 mm to 5 mm), depending on the purpose (Ferreira, Siegle, Ribeiro, Santos, & Grohmann, 2021). Its production takes place in the second generation petrochemical industries, which commercialize and transport them to the third generation manufacturing industries, where the most diverse products made up of plastic are manufactured. There are also recyclers, fourth generation industries that use plastic waste as a raw material and transform it into pellets, being inserted into the productive cycle again (Turra et al., 2020).

The increase in production and its different applications in the daily life of society, as well as its durability and low rate of degradation, have made this anthropogenic material a growing and persistent environmental problem (Massuga, Larson, Luis, & Doliveira, 2022; Okoffo et al., 2021; Orona-Návar et al., 2022). In addition to secondary microplastics (< 5 mm) resulting from the fragmentation of larger plastic waste, microplastics can also be derived from materials already produced with dimensions of less than 5 mm, such as pellets. They are categorized as primary microplastics and can be lost to the environment along the entire plastic production chain: production, packaging, storage, loading and unloading, transportation (truck spills, train cars and ships), processing and recycling (Fernandino, Elliff, Silva, & Bittencourt, 2015; Okoffo et al., 2021). These losses in the productive chain are being reported all over the world, for example, Cole and Sherrington (2016) reported the loss of 105 to 1054 tons per year of pellets in the UK production chain.

The first scientific articles about the occurrence of pellets in the environment were published at the beginning of the 1970s (Carpenter, Anderson, Harvey, Miklas, & Peck, 1972; Carpenter & Smith, 1972) and, in Brazil, was documented by Gomes (1973) on beaches in the south of the country. Since the issue of plastic pollution was first recognized in this period, studies of the impacts on marine biota have also become increasingly common in scientific circles, as microplastics are easily ingested by marine organisms due to their size (Harper & Fowler, 1987; Jiang, Conner, Lu, Tunnell, & Liu, 2022) being found in shellfish tissues (Ding et al., 2021), crustaceans (D’Costa, 2022), fish (da Costa, Costa, da Silva Oliveira, de Carvalho, & Zalmon, 2023; Digka, Tsangaris, Torre, Anastasopoulou, & Zeri, 2018), birds (Diaz-
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Santibañez, Clark, & Zavalaga, 2023) and mammals (Xiong et al., 2018). In addition, pellets can act as a source of contaminants to the organisms that ingest them, and can bioaccumulate and biomagnify in the trophic chain. These contaminants include chemical additives used by the plastic industry (e.g. plasticizers or flame retardants) and persistent organic pollutants present in seawater, which can be adsorbed onto the surface of the pellets (Diaz-Santibañez et al., 2023; Jiang et al., 2022).

The main sources of microplastics to the oceans can be marine and estuarine (ship spills and port facilities, for example) and, from land sources, through the runoff of urban drainage systems and rivers, transporting these beads to the coastal region (Ferreira et al., 2021; Moreira et al., 2016). The pellets are widely distributed around the world, and are commonly found in coastal regions (de Carvalho & Batista Neto, 2016; Diaz-Santibañez et al., 2023; Jayathilaka, Weerakoon, Indika, Arulananthan, & Kithsiri, 2022; Jiang et al., 2022), including remote locations where there are no polymer industries or ports, such as the Fernando de Noronha Archipelago (Ivar do Sul, 2014) and the Antarctic Peninsula (Lacerda et al., 2019). Due to their low density, pellets tend to float on the surface of the sea and winds, tides and currents contribute to their dispersion and transport over long distances from their place of origin (Gesamp, 2019). Part of this material, is deposited on the coastal zone by these environmental factors, and is incorporated into the grains of sand on the beaches. Storm events and geomorphology of the study areas also influence the concentration found (Gesamp, 2019; Jayathilaka et al., 2022; Lozoya et al., 2016).

Marine environments are the most studied as to pollution by microplastics (Kutralam-Muniasamy, Pérez-Guevara, Elizalde-Martínez, & Shruti, 2020). Although there is no global consensus on the methodology, most research involving pellets consists of analyzing the occurrence, abundance, physical characteristics and concentration of contaminants (Ferreira et al., 2021; Jiang et al., 2022). In Brazil, studies on the sediment from beaches have been mainly quantitative and qualitative (Moreira et al., 2016) and most collections concentrate in the intertidal zone and at the base of the dunes, sampling sediments both on the surface and in the subsoil, at depths of up to 2 m (Godoy et al. 2020; Jayathilaka et al. 2022; Schneider & Maffessoni 2021).

Research referring to microplastics in the state of Rio Grande do Sul is concentrated, as a priority, in the southern region of the state. On the middle coast, Pianowski, Silva, & Fillmann (1997), carried out a sampling in the Lagoa do Peixe Park, and found a large concentration of plastic beads, and, from this year onwards, there were no more collections in this coastal region. On the north coast, Schneider & Maffessoni (2021) collected sediment samples from three beaches: two urbanized beaches (Capão da Canoa and Torres) and one non-urbanized beach (Cabras), the latter, located further south from the north coast, showed the highest concentrations of pellets. The authors observed that, the further north of the state, the concentrations of pellets decreased, which may be related to coastal currents and at a distance from emitting sources, such as the Port of Rio Grande. Similarly, other authors (Balthazar-Silva et al. 2020; Ribeiro 2020; Turra et al. 2014) associate ports with the presence of pellets on beaches.

Whereas, in order to decrease the entry of microplastics into the aquatic environment, the sources of these materials need to be identified. And that the region of the middle coast of the state of Rio Grande do Sul lacks up-to-date studies referring to microplastics, besides being located between the researches carried out by Pianowski (1997) and Schneider and Maffessoni (2021), which linked the concentration of pellets found as a possible source the Port of Rio Grande. This study sought to evaluate the quantity of pellets on six beaches located between the Lagoa do Peixe National Park (Mostardas - RS) and Praia das Cabras (Cidreira - RS) and to analyze whether the quantity found will be smaller in the areas furthest from the Port of Rio Grande.
2 MATERIALS AND METHODS

The work was divided into definition of the study area with definition of the evaluation points and, collection and analysis of the results.

2.1 Field of Study

The study area is located in the Coastal Plain of Rio Grande do Sul, in the segment known as the middle coast, which extends for 275 km between the inlet of Dunas Altas and the Patos Lagoon. This region is sparsely populated, with small baths and fishing colonies, such as the resorts Mostardense, São Simão e Solidão, Praia do Mar Grosso and Farol (Alves, Viana, Ueno, Simões, & Filho, 2018).

Along the middle coast, six points were sampled (Figure 1), being the northernmost point (point 1) near the Balneário de Dunas Altas and the southernmost limit (point 6), bordering the Parque Nacional da Lagoa do Peixe, closest to the port of Rio Grande (approximately 160 km). The collection areas are 20 km apart between one area and another, in order to collect throughout this region. Also, they are not located close to the baths so there is no influence of urbanization, of summer activities and, consequently, of the underground of microplastics arising from the use of the beach strip.

Figure 1. Location of collection points of the middle coast segment, between the Lagoa do Peixe National Park and the Dunas Altas beach.
Source: Prepared by the authors (2022).
2.2 Sample Collection

The methodology used for this study was adapted from the research conducted by (Frias et al., 2018). The collection of sediment from the study areas occurred in spring/20 (A1), summer/21 (A2) and autumn/21 (A3). In order to relate the recent deposition of microplastics, the oceanographic conditions of the days preceding the collection and on the day of collection were recorded using data from the Windguru® platform.

Sampling took place on pellets recently deposited in the last tidal cycle, in the mark of the last primate (drop line). For each point, collections were performed in the morning in triplicates at the cue line and denominated as quadrant 1 (Q1), quadrant 2 (Q2) and quadrant 3 (Q3). With the use of a quadrant (1 x 1 m), the first two centimeters of sand were removed with the aid of a shovel. Each sample was sieved through a sieve with a 1 mm mesh and then packaged and identified, according to the beach and the place of collection. In the laboratory, for each sample, the material retained in the 1 mm sieve was dried in an oven at 100°C and, after drying, sieved on a sieve with a particle size of 4.75 mm. Subsequently, the material was separated and the pellets quantified.

3 RESULTS AND DISCUSSIONS

A quantitative evaluation of the pellets found was carried out and the origins and ways of managing these materials were discussed.

3.1 Quantities of Pellets Found

After analysis of the samples, 1,822 pellets were counted in the superficial sediment, considering the evaluated seasons. Of these, 96.26% were collected in spring/20; 3.741% in autumn/21, while in summer/21, no pellet was accounted for. In the six points sampled during the three collection campaigns, A1 and A3 were observed pellets at all points, while A2 were not found pellets (Board 1).

Although there are several researches on microplastics around the world, comparing the concentrations found in this study with other available data is difficult, since there is still no standardization as to the methodology for the collection, quantification and identification of pellets in sediments (Jiang et al., 2022; Van Cauwenberghe, Devriese, Galgani, Robbens, & Janssen, 2015). However, the results presented show values similar to those found in other surveys with the use of quadrants for the collections, but which differ in the number of points collected, the size of the quadrant and the locations of each point. Fernandino et al. (2015) and Lozoya (2016), for example, collected 1,927 and 912 pellets in the tidal line, respectively.

Board 1. Abundance of pellets sampled, by point and quadrant, in the sediment of beaches on the middle coast of Rio Grande do Sul, during the first (A1), summer (A2) and autumn (A3) collections

<table>
<thead>
<tr>
<th>Point</th>
<th>Collection A1</th>
<th>Collection A2</th>
<th>Collection A3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>1.</td>
<td>8</td>
<td>5</td>
<td>2.</td>
</tr>
<tr>
<td>2.</td>
<td>6</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>263</td>
<td>176</td>
<td>239</td>
</tr>
<tr>
<td>4.</td>
<td>32</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>5.</td>
<td>30</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>6.</td>
<td>723</td>
<td>32</td>
<td>134</td>
</tr>
</tbody>
</table>

Source: Prepared by the authors (2022).
For the A1 collection, the largest quantities obtained were at point 6, located further south and close to the Lagoa do Peixe National Park, with 889 units, followed by point 3 (678 units) and 5 (93 units). The expressive number for point 6 is due to Q1, where the largest quantities of all three collections carried out were found, with 723 units. It should be noted that in this quadrant and in point 3 (in the three quadrants) there was a lot of organic matter present, such as seaweed and branches, and most of the pellets collected were attached to these materials (Figure 2a).

A very common occurrence, reported in the study of Turner & Holmes (2011), where the authors found pellets stuck to other debris, such as string, wood, leaves and larger fragments of plastics and other waste. Under study of Sanchez-Vidal and collaborators (2021) it was found that the MPs remain stuck to the plants and, afterwards, are taken to the coast by the waves of the sea, mainly in stormy conditions. The result of collection A1 for point 6 was not repeated in A3, showing a lower number of pellets. In A3, the points with the highest quantities were: point 5 (24 un.), 6 (16 un.) and 4 (15 un.) and; in the other three points, less than 10 pellets were collected per point, being: point 1 (8 un.), 2 (4 un.) and only one unit in point 3. Comparing the presence of organic matter and other debris for the two collections, in the A3 collection there was no accumulation of these materials in the cue line (Figure 2c).

The results suggest that the conditions of the beaches on the day of collection and in the previous days influence the quantity of pellets available and this may be associated with the climatic factors of the day of collection and previous days. For all three seasons, wind direction was predominant northeast, but in the A2 collection, strong winds hit the coast with gusts greater than 60 km/h (40 mph) and strong winds also occurred in the days preceding collection. In this collection, the line of debris left by the last high tide was not observed, probably due to the winds, which may have carried the grains of sand and also other materials such as microplastics to other regions, such as the post-beach, or may have been carried back to the ocean (Figure 2b). However, in the A1 and A3 samples, the winds were weaker on the day and in the days prior to collection, with gusts of less than 35 km/h and pellets were observed in the line of leaves.
Likewise, the influence of the strong winds on the deposition of materials on the beaches has already been evidenced by various studies such as Ferreira and collaborators (2021) and Blond & Widmer (2017). The latter was also carried out in the southern region (Santa Catarina coast) and the authors concluded that the south quadrant winds cause the water to pile up on the coast, which contributed to the greater accumulation of garbage on the beach.

Godoy et al. (2020) and Maršić-Lučić et al. (2018) In their studies, they also show that the distribution of microplastics on beaches can be a result of various factors, such as geomorphological and sedimentary characteristics, as well as differences in exposure to the action of waves and wind. In order to contribute to the understanding of the concentrations found, as well as the conditions of the winds, the height and direction of the waves was also evaluated on the day of collection and in the days preceding the samples. Collection A1, which had the highest quantities, also showed the highest wave height (2 - 2.7 m), in the southeastern direction. In the A3 collection, the waves were smaller, between 1.1 and 1.7 m and with a southerly direction and the A2 collection, where no microplastics were found, the waves varied from 1.7 to 2.3 m with an eastern and southeastern direction. Comparing the A1 and A3 samples it is possible to evaluate that the greater wave height (in A1) may have helped in the greater deposition of materials on the beaches. On A2, on the other hand, where no pellets were collected, the force resulting from the relationship between the height and direction of the wave and the speed and direction of the winds may have culminated with the materials being carried to the higher regions of the beach or being buried.

Based on the results of this study, one can observe unequal distributions of pellets in the line of leaves, since, as stated above, deposition depends on several factors. Also, the cue line is not necessarily the main area of pellet accumulation. Various studies (Bancin, Walther, Lee, & Kunz, 2019; Moreira et al., 2016; Schneider & Maffessoni, 2021) they show that there is also
a deposition of microplastics in the region of the dunes, being carried out by the action of the winds or by waves during high tide that are pushing the materials to higher regions. And, since the microplastic particles are moved away from the coast, even larger waves of less frequent occurrence are needed to take them back to the ocean. These processes (strong winds and high waves) increase residence time and potentiate the accumulation of microplastics along beaches.

In order to understand the main locations of their microplastic deposition and to think about coastal management measures, it is important to identify the factors that influence this accumulation (Ryberg, Hauschild, Wang, Averous-Monnery, & Laurent, 2019). Ferreira and collaborators (2021) proposed a methodological approach to pinpoint the most favorable sites for the deposition of plastic pellets on beaches through an index and with geodesic precision. In a joint analysis of the altimetric, geomorphometric and meteoeceanographic aspects, the authors observed that the beach areas with altitudes higher than 2.06 m; slope ~ 3 and facing the same direction as the higher energy waves, were more susceptible to pellet deposition. In this condition, the very high energy waves reach the beach at an angle of ± 90, promoting the transport of the pellet and favoring its maintenance on the beach. Likewise, Eriksen and collaborators (2014), showed that the materials found on the beaches are the result of tilt, orientation, as well as the combination of wind force and direction. Given this, the rate of accumulation of debris on the beaches is sensitive to the sampling interval and to the environmental factors already described (Ferreira et al. 2021; Gesamp 2019; Moreira et al. 2016).

### 3.2 Pellet Management

The pellets are the raw material of the plastic industry, therefore their presence on the beaches is associated with losses during transport, loading/unloading and storage. Close to the area of study, Pianowski (1997) and Schneider & Maffessoni (2021) have already suggested that the presence of the Port of Rio Grande may contribute to the emission of pellets in the sediments of the beaches of Rio Grande, due to the traffic of ships along the coast. Likewise, in another region of the country, Balthazar-Silva et al. (2020) also attributed the pellets found in the study to the proximity of the Port of Santos.

In the present study, the results did not show a growing distribution pattern towards the port (Figure 3). Although points 1 and 6 had the lowest and highest concentrations, respectively, there was no progressive increase of pellets collected towards the southwest. Point 3 showed the second highest concentration, while the quantity found in points 4 and 5 were lower than point 3. It is worth highlighting that the collection areas of this research are not in the vicinity of the port (point 6 is approximately 160 km north of Porto), however, its activities may contribute indirectly with the deposition of pellets on the coast since it is to the south of the collection areas and, it may be that, through the coastal drift of sediment, which is predominant for NE, the pellets are carried to the beaches to the north of the port. In addition to geographic location, climate, tidal cycles, and oceanographic processes likely change patterns of pellet transport and distribution along the coast (Balthazar-Silva et al. 2020; Fernandino et al. 2015; Ribeiro 2020). This indicates that the accumulation and distribution of this pollutant on the beach is controlled not only by the proximity of the source and its physical characteristics, but mainly by extreme or storm events. And, in a similar way to what Ferreira and collaborators pointed out (2021) for the port of Santos, an increase in the frequency of storm events on the coast of Rio Grande do Sul, due to climate change, could worsen the deposition of this pollutant on the beaches near the port of Rio Grande.

It is also possible to consider that other ships coming from and bound for other ports pass through the coast of Rio Grande do Sul and may be losing pellets at sea. Furthermore, these materials show low density (generally composed of PP and PE) and their small size, high
energy events, such as storms, can remove them and send them floating back to the water. In this situation, hydrodynamic factors can redistribute them along the coast and run them aground on a beach far from their origin (Fernandino et al., 2015).

![Figure 3. Quantity of pellets per point, being the point 1 - farthest to the point 6 - closest to the port of Rio Grande. Source: Prepared by the authors (2022).]

The dispersion of the pellets in the sea exemplifies how the ocean regions all over the world are intimately interlinked (Jayathilaka et al., 2022). The results, therefore, highlight the importance of having management of pellet loss, since, this has already been reported in several studies in Brazil and worldwide showing that it is essential to consider its dangerous nature and its potential to cause harm to the environment (Jiang et al. 2022; Karlsson et al. 2018; Louro & Widmer 2017). Therefore, it is important to include handling practices and preventive measures, in addition to the need for regular regulation and inspections on ships and ports (Jayathilaka et al., 2022; Karlsson et al., 2018).

Worldwide, there are no regulations specifically dealing with pollution from plastic raw material losses during transport. However, most countries have some kind of legislation aimed at the general protection of environmental pollution. In Brazil, the principle of pollution prevention is present in the National Environment Policy - Law 6.938/1981 and, the National Policy of Solid Waste - Law 12.205/2010 regulates the generator of solid waste as responsible for the collection, storage, transport, transshipment, treatment or final disposal of solid waste, or final disposal of waste BRAZIL, 1981, 2010. Therefore, once the pellets are lost in the environment, it is the responsibility of the industry and its partners to contain the pollution caused by these materials. In this way, environmental responsibility must be shared among the whole chain (companies, producers, importers, transporters, among others), so as to ensure that the environment is preserved for the current and future generations (de Macêdo, de Moura, da Guia Santos, & de Oliveira Ribeiro, 2021).

Furthermore, the release of waste at sea is prohibited by Annex V of the 1978 MARPOL Protocol (IMO, 1973), a treaty that was created to prevent pollution and dumping of materials by ships. Oversight of spills at sea is difficult and complex, and it is vital to implement control programs and punitive measures for all companies involved in material handling to increase commitment to prevention and accountability after plastic spills (Balthazar-Silva et al., 2020; Karlsson et al., 2018).

An international initiative is the Operation Clean Sweep - OCS program created by the Plastics Industry Association (PIA) and the American Chemistry Council (ACC), with the
objective of reducing the losses of plastic resins through education and behavior change in the plastics industry. From this, the Zero Pellet Program - OCS® (PPZ-OCS®) arose in Brazil, which aims to engage the entire plastics sector in a continuous and effective action of containing pellets and other forms of resin, avoiding the contamination of bodies of water and consequently of the ocean, where plastic tends to accumulate. A plastic company can receive OCS® certification if the program is implemented according to Brazilian reality and under the parameters established in the "Forum Plastics Sector - By a Clean Sea", based on the original manuals of the program created in the United States (Implementation Manual of the Pellet Zero Program - OCS®, 2020). It is hoped that programs such as this will have wide-ranging repercussions and engagement in the fight against litter in the seas, a problem that is seen worldwide today as one of the priorities with regard to environmental preservation.

4 CONCLUSIONS

The data obtained in this study indicate that the average coastline of the state is continuous, since the first study in 1997, presenting pellets in its sandy sediment. Our findings suggest that the port regions are a source of pellets for the adjacent beaches, but it is essential to consider that these can be lost during their transport at sea and the currents and winds can transport them to different regions of the planet. In addition, it is of paramount importance to consider the distance from potential sources, oceanographic and geomorphological processes of the study areas, in order to assist in understanding the stranding and distribution of microplastics on sandy beaches. The exact pellet scattering paths are still unknown, extensive field observations in connection with other countries, while experiments in numerical modeling are recommended in future studies.

Finally, understanding the sources and factors (such as beach topography, climatic conditions, and others) contribute to our understanding of the distribution, abundance, and burial of plastic pollution. However, this information should help policy makers to plan better coastal management strategies so that better policies can be put into action. In view of the constant losses of this plastic material, it is fundamental to increase the responsibility for the prevention of pollution and to implement control programs in all the companies involved in the handling of pellets. That is, to address the global problem of marine plastic pollution, integrated measures involving the entire plastic value chain and different social actors (such as industry, government, civil society and academia) are needed.

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