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Plastic fragments as a major component of marine litter: a case study in Salvador, Bahia, Brazil*

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ABSTRACT

Urban areas are hotspots for marine litter. Plastic materials are the most common type of beach litter and can fragment into even smaller pieces. A total of 24 sampling stations were distributed along the coast of Salvador, Brazil, from which every litter item > 2 cm was sampled. A total of 17,089 items were sampled from the beaches of Salvador in two different survey seasons (10,416 during the winter and 6,673 during the summer). Plastic represented 87.45% of all materials sampled during the winter and 85.24%, during the summer. In both seasons, the majority of the sampled beaches were classified as extremely dirty according to the Clean-Coast Index. Plastic fragments were found in every sampling station in both field surveys, representing 45.7% of the overall plastic items sampled. Tourism/recreation activities appeared to be important sources of litter to the area.

Keywords: plastic pollution; plastic fragments; coastal management; urban beaches; coastal currents.

RESUMO

Fragmentos plásticos como um componente principal do lixo marinho: estudo de caso de Salvador, Bahia, Brasil

Áreas urbanas concentram lixo marinho. Materiais plásticos são o tipo mais comum de lixo de praia e podem sofrer fragmentação tornando-se cada vez menores. Um total de 24 pontos de amostragem foi definido ao longo da costa de Salvador, Brasil, nos quais todo item de lixo > 2 cm foi amostrado. A maioria das praias em Salvador está cobertas por lixo – tanto fragmentos quanto itens inteiros. Um total de 17.089 itens foi coletado das praias de Salvador durante duas campanhas (10.416 durante o inverno e 6.673 durante o verão). Plástico representou 87,45% de todo o material amostrado durante o inverno e 85,24% durante o verão. Em ambas as estações a maioria das praias amostradas foram classificadas como extremamente sujas de acordo com o Clean-Coast Index. Fragmentos plásticos foram encontrados em todos os pontos de amostragem em ambas as campanhas, representando 45,7% de todo o plástico encontrado. Atividades de turismo/recreação se mostraram fontes importantes para o lixo na área.

Palavras-chave: poluição por plásticos; fragmentos plásticos; gerenciamento costeiro; praias urbanas; correntes costeiras.

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1. Introduction

Litter can be found on beaches all over the world, originated from both local and distant terrestrial sources or brought ashore by the sea (marine source). According to Storrier *et al.* (2007) and Spengler & Costa (2008), sandy beaches, estuaries and the seafloor are the preferential areas for litter accumulation. Regarding beaches, marine debris can be deposited in the backshore in various situations, such as during spring high tides and events of equinoctial meteorological tides.

Longshore currents associated with swash transport of sandy particles and winds are the main agents responsible for longshore drift. In turn, the longshore drift controls sediment flow and budget (Komar 1976; Dominguez *et al.* 1983; Fontoura 2004). Analogously to the transportation of sediment particles, these currents can also transport litter, which can be deposited or redeposited, depending on factors such as seasonality, intensity of currents and litter density, in areas far from where they were originated.

Marine litter can be found in higher concentrations in the surrounding areas of great urban centers (Moore & Allen 2000; Leite *et al.* 2014). The proximity to urban centers is a determinant factor to its occurrence (Backhurst & Cole 2000).

Marine litter poses a clear threat to human well-being and various marine organisms. There are numerous reports of ingestion of marine litter by different species (*e.g.,* Colabuono *et al.* 2009; Provencher *et al.* 2010; Tourinho *et al.* 2010; Rebolledo *et al.* 2013; Buxton *et al.* 2013), which can cause their death and/or lead to the inclusion of the most minute particles of litter into food webs (Farrell & Nelson 2013), as well as cause entanglement (Gregory 2009). Marine litter also presents potential as a means for chemical pollution dispersion, due to the affinity of plastics in particular to different chemical compounds present in seawater (Ogata *et al.* 2009). Moreover, marine litter can also favor the occurrence of invasive species, which can use floating debris for dispersion (Barnes 2002).

An important component that is often overlooked in marine litter assessments are the plastic fragments, which represent a significant portion among the samples of beach litter monitoring surveys (Sobral *et al.* 2011). These fragments originate mostly from the abrasion of larger plastic items that were exposed to weathering in the marine and coastal environment (Sul & Costa 2014).

While whole items of marine litter allow surveys to narrow down potential inputs of these solid residues to the marine and coastal environment, fragments make source identification harder. For example, while cotton buds can be associated with sewage discharges, a nondescriptive piece of plastic does not tell such a simple story.

The general objective of the present study was to evaluate the occurrence and distribution of marine litter along the coastline of Salvador, state of Bahia, Brazil (Figure 1), emphasizing the contribution of plastic fragments as a major component of marine litter in order to understand the magnitude of the problem and optimize management efforts to address it.

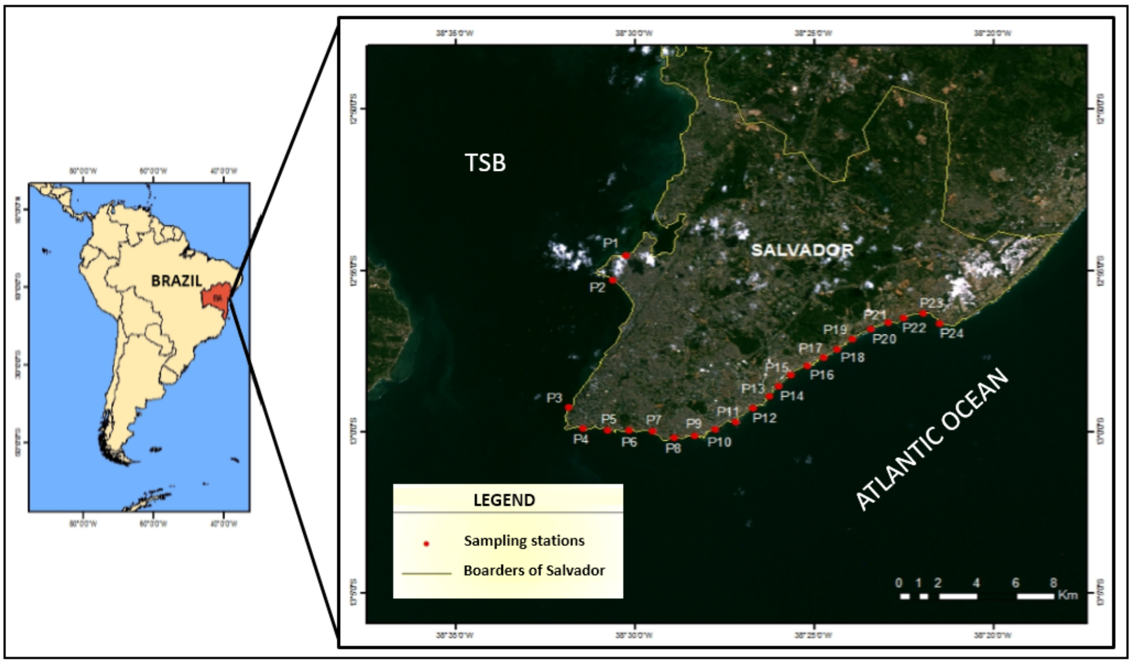

Figure 1 - Sampling stations along the coastline of Salvador, Brazil. TSB = Todos os Santos Bay.

Figura 1 - Pontos de amostragem ao longo da costa de Salvador, Brasil. TSB = Baía de Todos os Santos.

2. Study Site

With a growing population of over 2.6 million inhabitants, Salvador is one of the largest metropolises in the country (IBGE, 2010). The beaches of the municipality are also greatly sought out by tourists throughout the year, who visit them attracted by their natural beauty and the historical and cultural relevance of the city.

Along the coast of the state of Bahia, trade winds approach mainly from NE and E during the spring and summer, while during the autumn and winter, from SE and S (Bittencourt *et al.* 2008). During the autumn-winter period, SSE winds associated with the episodic approach of cold fronts reinforce SE trade winds. This atmospheric circulation system is responsible for the general pattern of wave fronts that approach the coast (Dominguez *et al.* 1992; Martin *et al.* 1998) and is also the main driver for the sediment dispersion pattern in this area. Geomorphological features indicate that this pattern respects the general NE - SW orientation of the net longshore drift in this area (Dominguez *et al.* 1992; Bittencourt *et al.* 2005).

However, locally, the direction of the general drift can be altered by the presence of promontories and rocky outcrops, generating local drift cells which do not necessarily respect the preferential direction of the net longshore drift. The area presents semidiurnal tides, with mean amplitude of 2.5 m reaching up to 2.8 m during spring tides.

3. Materials and methods

Two field surveys were performed during the winter of 2012 (from June to August – rainy season) and summer of 2013 (February – dry season), to investigate possible seasonality in the distribution and input of marine litter.

A total of 24 sampling stations were determined. Twenty-two stations were distributed every 1 km along the oceanic coastline of Salvador, from the Porto da Barra beach (P3), close to the mouth of the Todos os Santos Bay (TSB), up to the Itapuã Lighthouse (P24). The remaining 2 stations (P1 and P2) were located within the Todos os Santos Bay (TSB) (Figure 1).

A 10 m-wide transect was delimitated from the highest high water line to the end of the backshore, when encountering the first obstacle (*e.g.,* vegetation, frontal dune, wall, construction), in each sampling station (Figure 2). All litter (> 2 cm) was collected and stored in duly identified plastic bags. Pieces smaller than 2 cm are relatively difficult to be systematically sampled without using any equipment and are not sampled at this time. Sampling occurred early in the morning to avoid possible direct interferences of municipal cleaning activities.

Figure 2 - Representation of the transect delimited for sampling station P10.

Figura 2 - Representação do transecto delimitado para o ponto de amostragem P10.

Plastic items that were a fraction equal to 50% or less of the original object were counted as a fragment. Thus, the term "plastic fragment" in the present study is regardless to its size and should not be misinterpreted as "microplastic".

Litter was sorted and classified according to its composition (plastic, metal, glass, wood, cloth, others) and type of object (*e.g.,* plastic bag, beverage cans, barbecue wooden sticks, plastic fragments, etc.) in order to help in the identification of their potential sources (domestic/sewage/urban drainage, tourism/recreation, fisheries/boating activities, medical waste, indeterminate). The "indeterminate" source category encompasses not only items that can have multiple sources (such as plastic bags, for example, which can reach the beach through sewage/urban drainage or be dumped on the sand by a beach user, etc.), but also items which do not have a clear indication of potential source.

Until recently there was no global index to classify beach contamination by marine debris. Alkalay *et al.* (2007) proposed the Clean Coast Index (CCI) in order to classify beaches according to the amount of plastic on their sand since plastic is commonly the most abundant class of marine litter (Cheshire *et al.* 2009). Thus, to determine the CCI of each beach, first the density of plastics (*Dp*) was calculated as:

$$Dp = \frac{\textit{No. of plastic items}}{X\,(m) \times 10\,(m)} \qquad (1)$$

where X is the width of the transect.

In possession of this information, the CCI could be calculated using the equation:

$$CCI = Dp \times K \qquad (2)$$

where K is the correction coefficient (K = 20), used for statistical reasons and convenience, according to Alkalay *et al.* (2007).

The CCI results were then classified according to the pollution degree, from "very clean" (0 – 2), "clean" (2 – 5) , "moderate" (5 – 10) and "dirty" (10 – 20) to "extremely dirty" (> 20).

Density of plastic fragments (*Dpf*) was also calculated separately. This allowed for a better assessment of their occurrence and representativeness:

$$Dpf = \frac{\textit{No. of plastic fragments}}{X\,(m) \times 10\,(m)} \qquad (3)$$

where X is the width of the transect.

The Kruskal-Wallis test was used to asses significant differences between them amount of marine litter samples during each season.

4. Results

A total of 17,089 items were sampled. From these, 10,416 were sampled during the winter, and 6,673 during the summer. There was no significant difference ($p > 0.05$) between the number of marine litter items sampled during winter and summer.

During the winter, P5 (Figure 1) presented the highest density (31.50 items/m²) and P24, the lowest (0.19 item/m²). In turn, during the summer, P12 presented the greatest density (18.80 items/m²), and P24, once again, the lowest (0.33 item/m²).

The high occurrence of plastics (> 85% in both seasons) is in accordance to the numbers found in the literature (Cheshire *et al.* 2009), and guarantees the applicability of plastic as a proxy for the CCI. During the winter, the plastic category of materials was followed by metal (4.25%), while during the summer, by wood (4.87%).

During the winter, 87.5% of the beaches (21 stations) were classified as extremely dirty according to the CCI. The three remaining sampling stations were classified as dirty, moderate and clean, each representing 4.17% of the total. During the summer, extremely dirty beaches were also the majority (79.17%, 19 stations), followed by beaches classified as dirty (12.5%, 3 stations) and then moderate and clean (4.17%, 1 station each) (Supporting Information I).

The CCI values were commonly high above the number that indicates the highest category (CCI ≥ 20). During the winter, CCI values as high as 622 (P5) and 569 (P11) were found, while during summer the highest values were 350 (P12) and 280 (P8) (Table 1 in SI-I). This indicates the extreme degree of contamination of the beaches of the municipality which, in many occasions, are vastly covered by plastic items (Supporting Information II).

Regarding the potential sources of litter, during both seasons, all beaches presented greater representativeness of the category "indeterminate". This is the case of plastic fragments which, alone, represented a major portion of the samples (39.48% from the overall sampled material from both campaigns) and generally do not allow the identification of potential sources.

If the category "indeterminate" was not considered, during the winter, 23 (95.83%) out of the 24 sampled beaches had "tourism/recreation activities" as the main potential litter source. Still regarding the winter, only one sampling station had "domestic/sewage drainage" as the most representative class. In turn, excluding the category "indeterminate" in the summer campaign, 91.67% of the litter found on the beaches during this season was attributed to the category "tourism/recreation activities" and the remaining 8.33% to "domestic/sewage drainage".

Plastic fragments were found in every sampling station in both field surveys, with a mean of 185 fragments/sampling station (Table 1 in SI-I). During the winter, 4,446 fragments were sampled, while during the summer there were 2,302. Plastic fragments represented 45.7% of the 25 types of plastic items that were identified. This category was followed by polystyrene fragments (9.6%), cotton bud/lollipop sticks (9.4%), PET bottle caps (8.8%), cigarette butts (8.3%) and plastic cutlery/straws (6.4%).

During the winter the accumulation of plastic fragments was significantly higher. Peaks in plastic fragment abundance occurred in areas near rainwater drainages and sewage runoffs, such as in stations P1, P5, P7, P8, P10, P11 and P12 (Figures 1 and Supporting Information III).

5. Discussion

The greatest occurrence and density of marine litter were found during the winter. Because winter is the rainy season in this area, the number of tourists and general users of the beach is lower. However, the volume of water that can effectively runoff to the beaches, carrying litter, increases.

On the other hand, during the summer the use of the beaches in Salvador is greater and so is the effort of cleaning actions by local authorities. However, these activities are ineffective, especially regarding the removal of smaller plastic fragments, which usually escape the most common cleaning methods (raking) (Fernandino *et al.* 2015). In some cases, as reported by Leite *et al.* (2014), the frequency of cleaning efforts on the beaches of Salvador can significantly reduce the amount of litter on beaches, such is the case of Porto da Barra beach (P03), which is cleaned twice a day. Despite this effort, the beach in question was classified in the present study as extremely dirty with CCI = 28 at the moment of sampling. This indicates that the constant input to and fragmentation of marine litter at the adjacent marine and coastal environment is greater than the remediation actions. Thus, fighting the sources directly is necessary through sanitation, sewage treatment, municipal waste collection, and environmental education programs.

In many cases, the category “indeterminate” represented more than 80% of all sampled items. This reflects the difficulty in identifying the sources of contamination of the beaches in Salvador by marine litter. One reason for this finding is because the occurrence and characteristics of plastic fragments, as previously mentioned, do not allow for a more accurate identification of sources.

Sewage and rainwater drainages can be considered as important potential sources for plastic and plastic fragments to the beaches in the municipality considering the proximity of fragment concentration peaks to these areas.

The high concentrations of plastic fragments observed in stations P10, P11, P12, P23 and P24 may have resulted from a response to wave convergence zones (WCZ), as inferred by Fernandino (2014) who considered this factor as one of the responsible agents for plastic pellet concentrations along the same coastline. According to the same author, these WCZ are generated by wave fronts from SSE, SE and S, and are capable of casting small particles towards the continent, thus favoring their accumulation in the backshore.

As highlighted by Corcoran *et al.* (2009), the combination of particle transportation, both sediment and plastic, and flood tides result in the deposition of plastic particles along high water strandlines. However, this accumulation is temporary, because with the next high tide, marine litter previously brought and deposited, can be remobilized and deposited on a new strandline or float back on the surface of the sea. Thus, the usually more stable character of non-eroded backshores (i.e., presence of vegetation, primary dunes, etc.) can provide conditions that are more favorable for deposition and accumulation of particles, which was not a common condition observed in Salvador.

Litter found on the beaches of Salvador presents high mobility, since most of the sampling stations presented walls and other man-made structures constructed on the backshore within the range of spring tide high waters and meteorological tides, reducing the sand area where litter could be deposited for longer periods.

The great number of plastic fragments suggests long exposure of the plastic litter to weathering and mechanical agents. As reported by Sul & Costa (2014), the tendency that items in these conditions will fragment even more, originating microplastic, threatening various organisms which can ingest them either directly or indirectly, ultimately affecting top predators, such as human. It is clear that plastic, especially small fragments, have the potential of integrating the sediment matrix of sandy beaches, becoming an anthropogenic component of the sediment.

6. Conclusions

No evidence was found indicating that marine litter concentration was oriented according to the longshore drift. This could be explained by the constant presence of obstacles along the shore, which alter local coastal processes. However, WCZ and sewage and rainwater drainages seemed to influence areas of greater concentration of plastic fragments.

The coastline of Salvador, as a whole, was found to be polluted by marine litter, either in a greater or lower degree. Most of the beaches were classified as extremely dirty, despite the public cleaning activities that occurs along the beaches of the municipality. The CCI presented levels well above the minimum limit of the classification of extremely dirty (> 20) with values higher than 600. Such fact reflects the ineffectiveness of the current cleaning methods used by municipal cleaning agents.

Tourism/recreation activities were important sources of litter to the area. This finding suggests that measures and actions towards environmental education and awareness should be encouraged in order to change the behavior of the various beach users regarding marine litter production. The presence of items from domestic sources illustrates a lack of adequate sewage treatment and suggests the importance of an improvement in this sector in order to prevent its input and, consequently, improve both public and marine ecosystem health.

Analyzing the composition, size and characteristics of plastic fragments is important to understand its significance in the environment and, consequently, the threats posed by its presence.

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Appendix

Supporting Information associated with this article is available online at **http://www.aprh.pt/rgci/pdf/rgci-649_Fernandino_Supporting-Information.pdf**

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