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How many pellets are too many? The pellet pollution index as a tool to assess beach pollution by plastic resin pellets in Salvador, Bahia, Brazil*

Gerson Fernandino^{@, a}; Carla I. Elliff^a; Iracema R. Silva^b; Abílio C.S.P. Bittencourt^c

ABSTRACT

Plastic pellets are significant components of marine litter and can be found floating in the sea or stranded on beaches. However, current assessments of this issue lack standardization to allow comparisons of pellet pollution levels between different locations. Thus, the present study proposes the Pellet Pollution Index (PPI) to classify beaches based on the amount of pellets found in a given area of superficial sand. Pellets were sampled from 24 sites (P01 – P24) along the municipality of Salvador, Brazil, within a quadrat of 1 x 1 x 0.05m on the strandline and backshore. Twenty-two sites were located along the oceanic coastline, while the remaining 2 sites were within the Todos os Santos Bay. Results showed that, considering the coastline of Salvador as a whole, the PPI indicated a very low degree of pollution. This approach should aid future attempts of locating and removing the plastic anthropogenic component of the sediment on beaches and in marine environments.

Keywords: Plastic Pellets, Sandy Beaches, Pellet Pollution Index, Beach Pollution, Coastal Management

RESUMO

Quantos pellets são pellets demais? O índice de poluição por pellets como uma ferramenta para analisar poluição de praias por pellets de resina plástica em Salvador, Bahia, Brasil

Pellets plásticos são componentes significantes do lixo marinho e podem ser encontrados flutuando no mar ou encalhados em praias. No entanto, análises atuais dessa problemática não apresentam padronização que permita comparações de níveis de poluição por pellets entre diferentes locais. Assim, o presente estudo propõe o Índice de Poluição por Pellets (PPI) para classificar praias de acordo com a quantidade de pellets encontrados em uma dada área superficial de areia. Pellets foram amostrados em 24 pontos ao longo do município de Salvador, Brasil, dentro de um quadrado de 1 x 1 x 0,05m na linha de detritos e no pós-praia. Vinte e dois pontos se localizavam na orla oceânica, enquanto os 2 pontos restantes estavam dentro

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da Baía de Todos os Santos. Os resultados demonstraram que a orla de Salvador como um todo apresentava um grau muito baixo de PPI. Essa abordagem poderá auxiliar em iniciativas para a localização e remoção do componente antropogênico plástico do sedimento de praias e do ambiente marinho.

Palavras-chave: Pellets plásticos, praias arenosas, Índice de Poluição por Pellets, poluição de praias, gerenciamento costeiro.

1. Introduction

Industrial plastic pellets are composed of plastic resins – usually polyethylene, polystyrene or polypropylene, that are 2 – 5 mm in diameter and are used as raw material in the production of plastic items (EPA 1993; Ogata *et al.* 2009). These spherules can reach the marine environment, and eventually become deposited on sandy beaches, during their production, transport or use. Due to their small size and resemblance to food items, plastic pellets are ingested by a wide range of marine organisms (Tourinho *et al.* 2010; Buxton *et al.* 2013; Rebolledo *et al.* 2013). In addition, chemical compounds in the sea water, such as persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and pesticides can become absorbed onto the pellets which, when ingested, may trigger bioaccumulation (Ogata *et al.* 2009; Yamashita *et al.* 2011) and biomagnification processes (Endo *et al.* 2005; Frias *et al.* 2010; Karapanagioti *et al.* 2011), posing threats especially to apex predators, which include marine animals and humans.

Until recently, marine litter assessments in general focused on quantifying and qualifying the sampled material, but there was no index which classified sandy beaches according to their pollution degree by solid waste. Thus, Alkalay *et al.* (2007) proposed the Clean Coast Index (CCI) to classify sandy beaches according to the amount of plastic present in beaches. Furthermore, they determined that plastic debris could be used as a proxy for all types of litter, because plastic is the most abundant material comprised in marine litter. However, this classification does not encompass plastic pellets in its calculation, since only particles larger than 2 cm are considered.

Various studies have been conducted worldwide concerning the presence of plastic pellets on beaches focusing mainly on the quantification of pellets (Gregory 1977, 1978; Shiber 1979, 1982; Shiber & Barrales-Rienda 1991; Ivar do Sul *et al.* 2009; Costa *et al.* 2010; Turner & Holmes 2011; D'Antonio *et al.* 2012) and their external/physical (Corcoran *et al.* 2009; Fotopoulou & Karapanagioti 2012) or chemical characteristics (Endo *et al.* 2005; Ogata *et al.* 2009; Frias *et al.* 2010; Karapanagioti *et al.* 2011; Lithner *et al.* 2011; Rochman *et al.* 2013). However, no studies were found in the literature that classified sandy beaches according to pollution (presence) by pellets. This hinders the communication, both for the scientific community and general

population, of the information provided by various studies that observed the abundance of this material in a variety of beaches worldwide. Similar to what motivated the creation of the CCI, plastic pellet evaluations still lack a tool that allows the classification of a beach according to its degree of pollution by pellets. Thus, we propose the Pellet Pollution Index PPI and apply to beaches of the municipality of Salvador, Brazil.

2. Materials and Methods

2.1. Sampling site

The municipality of Salvador has a coastline of approximately 40 km (Figure 1), which is characterized by the presence of more rectilinear sectors (i.e. the sector between P15 – P17 and P18 – P21), promontories (i.e. near P05), and sectors with pocket beaches (i.e. Paciência Beach, P08) that are intersected by rocky outcrops, both basement rock and beach sandstone.

Salvador is a metropolis with over 2.6 million inhabitants (IBGE 2010). The municipality's beaches, especially those located within the Barra district (P03 and P04 in Figure 1), are intensely used by tourists and local beachgoers, attracted by both the natural beauty and the historical and cultural relevance of the region.

The coastline is highly urbanized, with very few well established backshore areas due to the presence of anthropogenic structures to support the beachside avenue. As shown in Figure 1, there are numerous urban river and rainwater drainages that discharge straight on the municipality's beaches. According to Fernandino (2014), in addition to fulfilling their role in draining water to the ocean, these drainages represent a source of litter and potentially also pellets to the marine environment, because industries that use plastic pellets as raw-material can easily lose some of this material during handling.

2.2. Pellet sampling

Plastic pellets were sampled from the beaches of Salvador during the rainy season (winter) of 2012 (June to August) and the dry season (summer) of 2013 (February). A total of 24 sites were sampled: 22 sites every 1 km along the coastline of Salvador extending northwards from the Porto da Barra beach (P03), at the entrance of the Todos os Santos Bay (TSB), to the lighthouse in Itapuã (P24) (see Figure 1). In addition, two sites located within the TSB were sampled, Ribeira (P01) and Boa Viagem (P02), in order to compare the

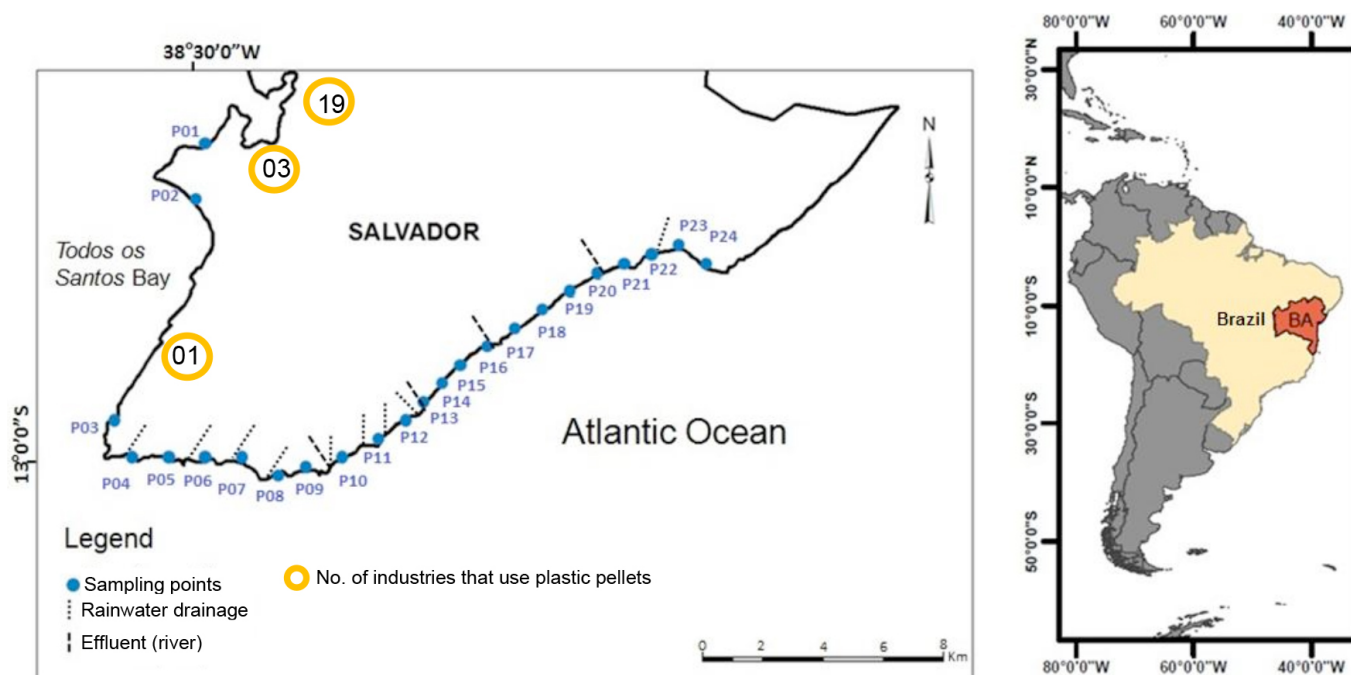


Figure 1 - The study area showing sampling sites.

Figura 1 - Localização da área de estudo e pontos de amostragem.

concentrations of plastic pellets with open coastline sites, particularly due to the presence of the port of Salvador.

At each site, a 1 x 1 x 0.05 m quadrat was placed on the strandline of the last recent high water mark and a second one was surveyed by the landwards obstacle that limited the sand strip. This obstacle could be either natural (e.g. vegetation or dunes) or anthropogenic (e.g. walls and other constructions). This landwards area was generically called “backshore” in the present study. The superficial layer of sediment within the quadrat, respecting the maximum depth of 0.05 m, was removed and immersed in a bucket with seawater to separate the plastic pellets through flotation. This superficial sampling was chosen in order to evaluate recent deposition of plastic pellets for future inference of hydrodynamic-meteorological factors and/or events which governed their deposition. As reported by Turra *et al.* (2014), the distribution of pellets throughout the sediment column is variable, and, as such, the index proposed in the present study should be applied to the uppermost strata of sediment to avoid over or underestimating the level of pollution.

2.3. Data Analysis

The data collected were digitized and primarily analyzed using a worksheet on the software Excel (Windows Office 2010). The statistical analysis of the abundance (i.e. absolute number of pellets) and concentration (i.e. number of pellets per m²) of pellets was performed through the Kruskal-Wallis test (BioEstat. 5.3) in order to verify the existence of significant differences between the sampled seasons.

2.4. Pellet Pollution Index - PPI

The calculation of the PPI was performed as shown in Equation (1), using the ratio between the number of pellets and the volume of sediment sampled. This ratio was then multiplied by a correction coefficient p ($p = 0.02$), arbitrarily determined to conveniently classify the result within a range of 0 to 3 according to the degree of pollution as follows: very low ($0.0 < PPI \leq 0.5$); low ($0.5 < PPI \leq 1.0$); moderate ($1.0 < PPI \leq 2.0$); high ($2.0 < PPI \leq 3.0$); and very high ($PPI > 3.0$).

$$PPI = \left[\frac{n \text{ (items)}}{a \text{ (m}^2\text{)}} \right] \times p, \quad (1)$$

where n is the amount of sampled pellets, a is the area of sampled sediment and p is the correction coefficient.

Table 1 presents the classification of the degree of pollution by pellets and the numerical abundance. The column with numerical data was included in order to provide a comparative numerical order of magnitude between raw data and the index.

In cases where the strandline and the backshore overlapped, due to the interruption of the backshore by anthropogenic obstacles, only one quadrat was sampled. Thus, for the calculation of the PPI, the area of sediment for those sites corresponded to half the area of the other sites.

3. Results and Discussion

In total, 1,967 pellets were sampled from the beaches of Salvador. Of these, 1,102 were sampled during the winter of 2012 and the remaining 865, during the summer of 2013. From the 24 sampled sites 20 presented plastic

Table 1 - Concentration of pellets and Pellet Pollution Index (PPI) classification.

Tabela 1 Concentração de pellets e classificação pelo Índice de Poluição por Pellets (PPI).

PPI	Concentration of pellets	Classification
$0.0 < \text{PPI} \leq 0.5$	0 – 25	Very Low
$0.5 < \text{PPI} \leq 1.0$	25 – 50	Low
$1.0 < \text{PPI} \leq 2.0$	50 – 100	Moderate
$2.0 < \text{PPI} \leq 3.0$	100 – 150	High
$\text{PPI} > 3.0$	> 150	Very high

pellets deposited on the superficial layer of sand (83.33%) during the winter, and 18 (75%) contained pellets during the summer.

The mean number of pellets observed at each site was 45.92 (SE = 12.89) during the winter of 2012 and 36.04 (SE = 9.66) during the summer of 2013. During the winter, the site with greatest abundance was P11 (Pituba beach; 265 pellets), followed by P16 (Boca do Rio beach; 155 pellets), and by P12 (Jardim dos Namorados beach; 129 pellets). During the summer, site P04 (Barra beach) presented the greatest abundance, with 196 pellets, followed by P16 (Boca do Rio beach; 125 pellets), and by P07 (Paciência beach; 79 pellets). During the winter, P01 (Ribeira beach), P02 (Boa Viagem beach), P23 (Itapuã beach) and P24 (Farol de Itapuã beach) did not present pellets. During the summer, sites P01 (Ribeira beach), P03 (Porto da Barra beach), P05 (Othon Hotel beach), P22 (Piatã Duna beach) and P24 (Farol de Itapuã beach) did not present pellets. The number of total pellets collected did not vary significantly ($p > 0.05$) between summer and winter.

The very low concentration of pellets on the beaches located towards the TSB during the studied seasons suggests that either the port area/activities are not a major source of pellets for those beaches or the circulation patterns of the TSB do not provide conditions which allow for their deposition at these locations. Moreover, as mentioned previously, the constant presence of urban river drainages and effluents that discharge straight onto the municipality's beaches can also represent a source of pellets, which could explain the absence of pellets in P24, for example, since there are no drainage outputs on this site.

Plastic pellets were sampled from a total of 86 m² of superficial sediment. Thus, an overall mean value of 23.26 pellets m⁻² (SE = 4.6) was obtained for the entire coastline, which results in a PPI of 0.46, meaning a very low degree of pollution by plastic pellets. The density of pellets sampled during the winter of 2012 was higher (26.20 pellets m⁻², SE = 7.61, PPI = low degree) than during the summer of 2013 (20.31 pellets m⁻²,

SE = 5.27, PPI = very low degree). The PPI was determined for each site as shown in Figure 2.

During the winter, most of the sampled sites (75%) presented a very low PPI. The categories “low”, “moderate” and “high” each represented 8.33% of the total of sampled sites. During the summer, 66.67% of the sites were classified as having a very low PPI, followed by the classifications “low” (20.83%) and “moderate” (12.5%). No sites presented “very high” PPI in either season.

In order to assess the applicability of the PPI as a tool for improving the comparison of results obtained from different study sites, the index was used to classify several national and international studies gathered through literature review (Table 2). The values for pellet density (No. pellets m⁻²) were either directly provided by the authors in the consulted literature or had to be calculated using the information available in each article (sampling area in m² and number of sampled pellets).

By standardizing the measurement of the occurrence of pellets on sandy beaches it is possible to observe that this type of pollution varies immensely. The frequency of a very high degree of pellet pollution observed on several beaches is concerning. This finding should encourage studies to also identify the possible sources of pellets in the environment and propose mitigation strategies to improve the situation.

The urbanized characteristics of the coast of Salvador do not seem to favor long-term deposition of pellets on sandy beaches, because along various sectors of the coast the area that should correspond to the backshore is replaced by walls that support the beachside avenue. However, the absence of a well-developed backshore did not seem to be a determinant factor for pellet deposition – at least recent deposition –, considering that sites such as P12 (Jardim dos Namorados beach) presented a high concentration of pellets during the winter, despite the anthropogenic obstacle (wall) being within reach of high water swash. At sites such as P14 (Jardim de Allah beach) and P15 (Aeroclube beach) which contain a wider sand strip and a better developed vegetated backshore, characteristics that are theoretically more favorable for deposition, the PPI was very low and low (winter and summer, respectively), whereas other sites with the same characteristics (e.g. P16 – Boca do Rio beach) presented higher concentrations.

The difference between classifications is most likely a reflex of a number of factors. However, as reported by Turra *et al.* (2014), pellet distribution patterns on sandy beaches appear to be more related to oceanographic processes than anthropogenic processes. Therefore, it is reasonable to infer that the characteristics of each season and beach, such as the presence of a well-developed backshore and the exposure to waves, alter the transport

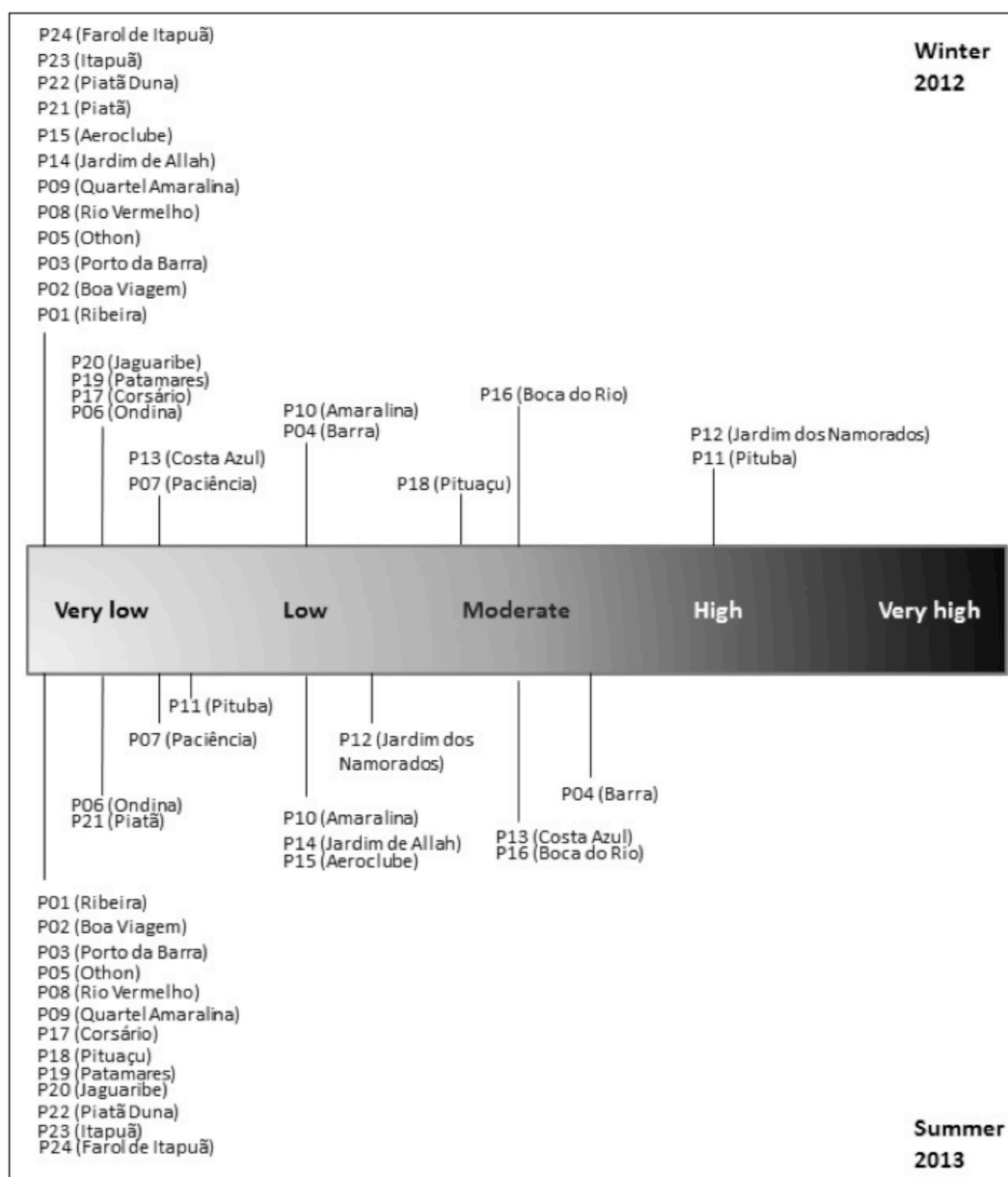


Figure 2 - Pellet Pollution Index (PPI) for 24 beaches in the municipality of Salvador during the winter of 2012 and summer of 2013.

Figura 2 - Índice de Poluição por Pellets (PPI) em 24 praias do município de Salvador durante o inverno de 2012 e verão de 2013.

and deposition patterns of pellets along the coast of Salvador, thus influencing the degree of pollution by this plastic item. Another important factor to be considered is the fact that, due to the low density of pellets (usually composed by PP and PE) and their small size, high-energy events such as storms can remobilize them and send them floating back to the surf zone or open water. In this situation, hydrodynamic factors may redistribute them along the same shoreline or strand them on a beach located far from their origin.

4. Conclusions

The coast of Salvador is polluted by plastic pellets to higher and lower degrees. The results determined through the use of the Pellet Pollution Index seem to

reflect the reality experienced in the field, where beaches with a great number of pellets visible to the naked eye presented a higher PPI. The very low degree of pellet pollution on the beaches located within the TSB (P01 – Ribeira beach and P02 – Boa Viagem beach) during both seasons allows a reasonable inference that the port of Salvador is probably not a relevant source of pellets to the local marine environment. Although the majority of industries that use plastic pellets are also located near sites P01 and P02 they do not seem to be local sources of pellets for the sites. However, eventual pellets spills or inappropriate disposal in the sewage system could carry pellets to farther beaches.

Detailed information concerning sewage/drainage system are important in order to identify areas of greater

Table 2 - Use of the Pellet Pollution Index (PPI) in various studies. Number of rows for each study represents the number of sampling sites.

Tabela 2 - Uso do Índice de Poluição por Pellets (PPI) em vários estudos. O número de linhas em cada estudo representa o número de pontos/locais de amostragem.

Author(s)	Study area	Density (pellets/m ²)	PPI	Classification
Costa <i>et al.</i> , 2010	Brazil	222.22	4.44	Very High
		44.44	0.89	Low
		100.00	2.00	Moderate
D'Antônio <i>et al.</i> , 2012	Brazil	262.22	5.24	Very High
		1636.67	32.73	Very High
		146.67	2.93	High
		351.11	7.02	Very High
		906.67	18.13	Very High
		95.56	1.91	Moderate
Gomes, 1973	Brazil	31.75	0.64	Low
Lima, 2012	Brazil	154.00	3.08	Very High
		505.00	10.10	Very High
		281.00	5.62	Very High
		103.00	2.06	High
		63.00	1.26	Moderate
		95.00	1.90	Moderate
		383.00	7.66	Very High
		270.00	5.40	Very High
		84.00	1.68	Moderate
		48.00	0.96	Low
Manzano, 2009	Brazil	5.00	0.10	Very Low
		15.00	0.30	Very Low
		2.00	0.04	Very Low
		8.00	0.16	Very Low
		3.00	0.06	Very Low
		58.00	1.16	Moderate
		0.80	0.02	Very Low
		15.00	0.30	Very Low
Turner and Holmes, 2011	Maltese Islands	0.70	0.01	Very Low
		167.00	3.34	Very High
Zbyszewski <i>et al.</i> , 2014*	North America (Lake Erie)	0.36	0.01	Very Low
		0.02	0.00	Very Low
		0.24	0.00	Very Low
		0.00	0.00	Very Low
		0.03	0.00	Very Low
		0.39	0.01	Very Low
		0.90	0.02	Very Low
		2.03	0.04	Very Low
		1.00	0.02	Very Low
		0.60	0.01	Very Low

Table 2 - Use of the Pellet Pollution Index (PPI) in various studies. Number of rows for each study represents the number of sampling sites. (Cont.).

Tabela 2 - Uso do Índice de Poluição por Pellets (PPI) em vários estudos. O número de linhas em cada estudo representa o número de pontos/locais de amostragem. (Cont.).

Author(s)	Study area	Density (pellets/m ²)	PPI	Classification
	North America (Lake St. Clair)	0.01	0.00	Very Low
		0.00	0.00	Very Low
		0.01	0.00	Very Low
		0.00	0.00	Very Low
		0.89	0.02	Very Low
	North America (Lake Huron)	33.23	0.66	Low
		1.47	0.03	Very Low
		0.57	0.01	Very Low
		0.14	0.00	Very Low
		0.00	0.00	Very Low
		0.00	0.00	Very Low
		0.00	0.00	Very Low

risk of pellet input into the environment, as well as to identify sources and allow for mitigation. Information regarding the characteristics of the material such as types of plastic resins (polyethylene and polypropylene, for example), as well as the main color of the pellets that nearby plastic industries use in their production processes, can be important in order to verify if the pellets found stranded on Salvador's beaches present the same characteristics.

Although Salvador presents highly urbanized beaches in which periodic cleaning activities are performed by the local government using mainly rakes, the presence of pellets on these beaches also suggests that the current cleaning methods are not effective in removing small items that increasingly accumulate on the sand. This raking is not performed thoroughly along the entire coast due to its extent and the limited number of cleaning agents involved. It usually focuses on short stretches of beach where macro marine litter accumulation can be spotted near touristic beaches. Generally, two or three people, who cover a long stretch of beach (approximately 2 km), perform this cleaning method. While one of these people roughly rakes the sand for large plastic items and gathers them in small piles, the remaining two people follow the first and collect the debris in plastic bags. In some cases, a tractor comes later to gather the bags, or the same people take the bags with them to the nearest garbage pick-up location. Due to the space between the teeth of the rakes (usually > 1 cm) this tool has little ability of removing pellets from the beach. On the other hand, the rakes can bury the pellets under a thin layer of sediment. However, because the methodology used in the present study consisted of sampling the superficial 5 cm of sediment, this factor was minimized.

Analyzing the composition, size and characteristics of marine litter is important to understand the significance of its presence in the environment and, consequently, the threats imposed by it. The PPI proved to be a useful and easily applicable tool with great potential in evaluating and monitoring the level of pollution by pellets on the surface of sandy beaches. The use of the PPI seemed to be suitable for other places around the globe, aiding in the comparison of results, which can be difficult due to lack of standardization. Moreover, the index can be a useful tool to assess the environmental quality of beaches, indicating the degree of pollution by plastic pellets.

Such information could help future attempts of removing the anthropogenic plastic component from beach sediments and other marine environments.

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