Anthropogenic Litter on Beaches With Different Levels of Development and Use: A Snapshot of a Coast in Pernambuco (Brazil)

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This research aimed to evaluate anthropogenic litter found on beaches with different levels of development and use along the coast of Pernambuco (northeast Brazil) to determine patterns in composition and origin. The study was conducted in January 2013 at nine beaches classified into three groups according to the level of urbanization. At each beach, three sections measuring 100 m long and 1 m wide were defined along the high-tide waterline where all items of anthropogenic litter larger than 2 cm were visually counted and classified. The sections were separated by intervals of 100 m. Within each 100 m section, random stretches of 10 m were selected where all the visible plastic fragments with sizes between 0.5 and 2 cm were collected and bagged for subsequent counting. Sources of anthropogenic litter were divided into three categories, namely beach users, land-based (houses/residences), mixed, and fisheries. A total of 12,815 items were found on the nine beaches within the three transects on each beach (one survey per beach), with densities (items/m^2) of 2.3, 5.7, and 6.3 for groups 1, 2, and 3, respectively. The most-represented items of anthropogenic litter in the evaluated samples were plastic, food scraps, and wood (wooden skewers). With respect to items composed of plastic, the majority were cigarette butts (45%). Additionally, cigarette butts made up 26% of all anthropogenic litter samples collected. A larger amount of fragments smaller than 2 cm occurred in all beaches; for this size fraction, the densities were 0.6, 0.5, and 0.76 items/m^2 for groups 1, 2, and 3, respectively, which were 1.5, 2.5, and 1.65 times higher, respectively, compared to those of fragments larger than 2 cm. The beaches with lower levels of urbanization also had smaller quantities of anthropogenic litter. Items related to beach users were predominant for most of the beaches. The confirmation that beach users are primarily responsible for the generation of anthropogenic litter may contribute to the development of strategies to reduce the problem, such as installing bins and distribution containers for anthropogenic litter collection and designing educational campaigns for beach users.

Keywords: coastal environments, marine pollution, marine litter, plastic litter, beach users

INTRODUCTION

Beaches are used by different social groups with diverse interests. The level of use of each beach varies based on several factors (Tudor and Williams, 2006; Oh et al., 2010). The different levels of beach usage are mainly determined by factors such as proximity to urban centers and ease of access (Paula et al., 2013), infrastructure availability (Silva et al., 2013), and frequency of routine cleaning of the area (Pendleton et al., 2001; Nelson and Botterill, 2002; Tran et al., 2002; Tudor and Williams, 2006). The rapid growth in coastal development, stimulated by tourism and residential expansion, often results in dense population and infrastructure that can cause resource degradation and pollution (Lithgow et al., 2014; Botero et al., 2015). Beach quality assessments are often related to user perception, and aesthetic values, such as hygiene and cleanliness, are their main concerns (Lozoya et al., 2014; Botero et al., 2015) despite current environmental conditions (UNEP, 2005, 2009, 2016; Scisciolo et al., 2016).

Brazil is endowed with high tourism potential owing to its 8,500 km coastline, along which the population is concentrated (IBGE, 2011). Therefore, Brazilians are regular visitors to beaches and enjoy the low cost of this type of entertainment and the mild climate of most states. Zuanazzi (2016) evaluated the floating population in 11 coastal municipalities of Rio Grande do Sul during the summer period, and found that the total amount of people increases from 207 thousand to more than 500 thousand. In some cases, the population increase is over 400%.

The occurrence of anthropogenic litter in coastal areas (populated or not) has been reported globally by numerous researchers, and is highlighted as a growing threat (Debrot et al., 1999; Coe and Rogers, 2000; Araújo and Costa, 2007a; Moore, 2008; Galgani et al., 2014; Scisciolo et al., 2016). Anthropogenic litter deposited on beaches usually has several sources. As such, it may have originated from rivers that flow into the area, from users, or from the sea itself through currents and wind (Ivar do Sul and Costa, 2007; Moore, 2008).

Although the occurrence of anthropogenic litter on beaches can be related to several factors, such as location and morphology of the beach, the presence of rivers and streams, and winds, the contribution of users is proven and has been reported in numerous studies (Santos et al., 2003; Araújo and Costa, 2007a; Silva et al., 2008, 2015, 2016; Silva-Cavalcanti et al., 2009; Dias Filho et al., 2011; Scisciolo et al., 2016; Wilson and Verlis, 2017). Urban beaches are typically littered with cigarette butts, food wrappers, cups, plastic straws, and beverage cans (Williams and Simmons, 1997, 1999; Araújo and Costa, 2006; Silva et al., 2008; UNEP, 2009, 2016; Ivar do Sul and Costa, 2013; Ivar do Sul et al., 2014; Leite et al., 2014). The presence of a large number of users is also responsible for greater commercial exploitation of beaches. Commercial activity has been developed in these environments, especially related to the sale of food and beverages. This activity forms a constant source of anthropogenic litter that is often discarded on the beach itself (Araújo et al., 2012).

The intense use of natural environments such as beaches is almost always accompanied by irregular anthropogenic litter disposal (Santos et al., 2003; Araújo and Costa, 2007a; Silva et al., 2008, 2016; Silva-Cavalcanti et al., 2009; Vieira et al., 2011; Scisciolo et al., 2016; Wilson and Verlis, 2017). Especially in urban beaches, the accumulation levels of solid residues are related to the arrival of visitors. Marshall et al. (2014) stated that the proximity of an urban environment to a beach is of particular importance as a source of anthropogenic pressure on the beach.

Anthropogenic litter may be responsible for economic, social, and environmental damage, such as expenditure incurred by public agencies to clean beaches instead of using these funds for other areas in need (Araújo and Costa, 2006), loss of aesthetic value and tourism potential of the sites (Araújo and Costa, 2007a; Silva-Cavalcanti et al., 2013), pollution by pathogenic agents (Zuza-Alves et al., 2016), and damage to marine biota by accidental ingestion and entanglement, which can cause choking, injury, illness, and death of marine organisms (Moore, 2008; Attademo et al., 2015; Mendes et al., 2015). Along with other forms of extremely harmful pollution, plastics present in anthropogenic litter are one of the biggest concerns for the ocean in terms of marine pollution because of their intrinsic properties, such as low density (which facilitates their fluctuation and consequent dispersion), persistence, cumulative build-up over time, and widespread use (Moore, 2008; Corcoran et al., 2009; Thompson et al., 2009; Scisciolo et al., 2016). To determine the source of anthropogenic litter, researchers must know their location and use, assess the quantity and composition of anthropogenic litter, and relate these data to the environmental and socioeconomic characteristics of the area. Identification of the sources of anthropogenic litter is fundamental for planning strategic actions to minimize the problem (Pasquini et al., 2016).

This research aimed to evaluate anthropogenic litter found on beaches with different levels of development and use along the coast of Pernambuco (a state in northeast Brazil) in order to determine patterns in composition and origin and to answer the following questions. (i) Is there a relationship between beach use/development and anthropogenic litter? (ii) Apart from the larger items, is there a large number of small plastic fragments, which pose particular threats?

MATERIALS AND METHODS

This study was conducted in January 2013 at nine beaches located along the coast of Pernambuco (**Figure 1**), which were classified into three groups according to the level of urbanization (**Table 1**), namely Low (Forte Orange, Maracaípe, and Carneiros), Medium (Porto de Galinhas, Maria Farinha, and Campas), and High (Bairro Novo, Boa Viagem, and Piedade).

The beach groups differed from each other with respect to the level of urbanization, use, and environmental conditions (**Table 1**).

At each beach, three sections (replicates) measuring 100×1 m of the strandline (maximum level reached by the tide and where anthropogenic litter was deposited) were sampled based on Silva-Cavalcanti et al. (2009, 2013) and Jayasiri et al. (2013). The sections were separated by intervals of 100 m. In each section, all items of anthropogenic litter larger than 2 cm were visually counted and classified according to their composition (plastic,
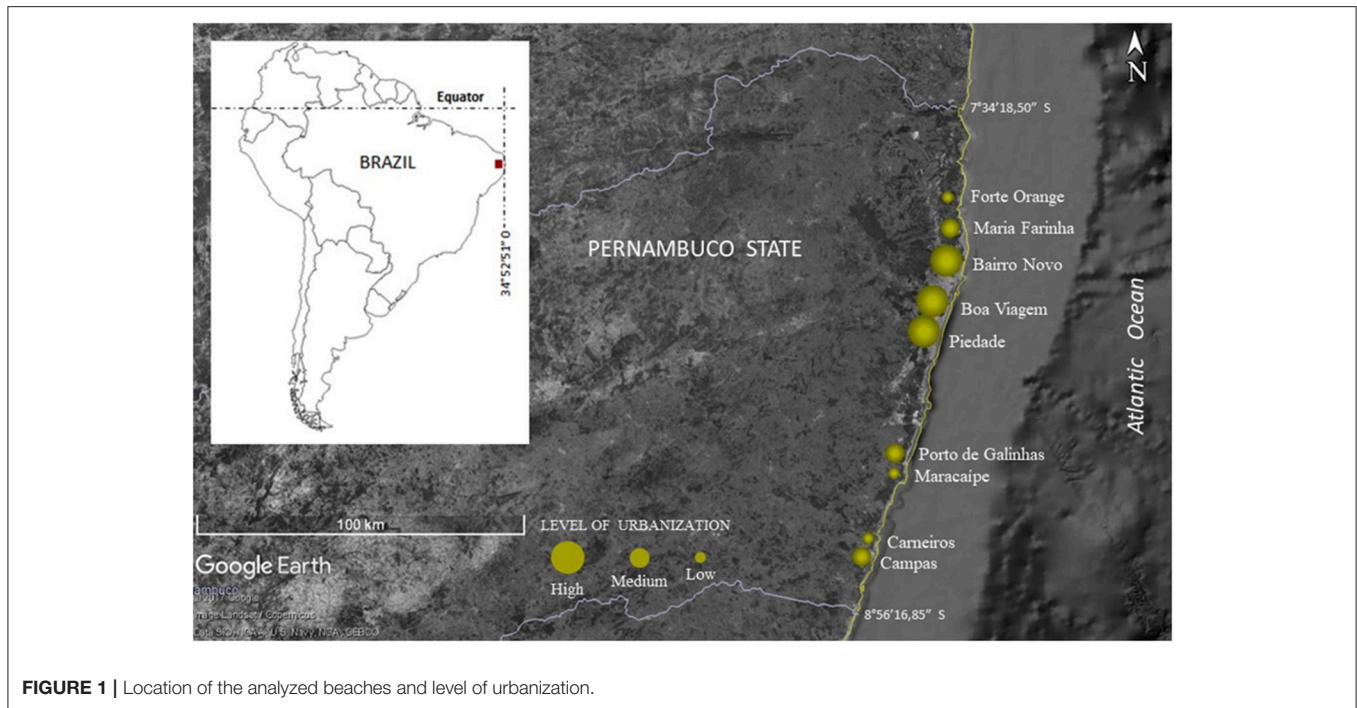
FIGURE 1 | Location of the analyzed beaches and level of urbanization.

TABLE 1 | Characteristics of the studied beaches based on type of use and occupation of land, which determined the environmental conditions of the studied area (Araújo and Costa, 2008).

Group	Level of urbanization	Beaches	Characterization of urban occupation and use	Environmental conditions
1	Low			
		Forte Orange	Nearby small-sized urban centers.	Foreshore and backshore preserved.
		Maracaípe	Few residences	Many stretches of preserved vegetation.
		Carneiros	Low use and largely confined to periods of high season (December to March).	
			Low informal commercial activity.	
2	Medium			
		Maria Farinha	Close to medium-sized urban centers with	Reduction of foreshore and backshore in some
		Porto de Galinhas	predominance of homes (<2 floors) and	stretches.
		Campas	hotels.	Reduction of native vegetation areas.
			High use during periods of high season, and lower use in other seasons.	
			Moderate informal commercial activity.	
3	High			
		Bairro Novo	Urban beaches	Fore shore and backshore reduced.
		Boa Viagem	Beachfront almost completely verticalized.	Lack of native vegetation.
		Piedade	High use during the whole year.	Erosion
			High informal commercial activity.	

glass, metal, paper, wood, and food/organic). Categories were used to identify the most likely sources of anthropogenic litter based on Silva-Iñiguez and Fischer (2003). The categories were beach users, land-based (houses/residences), mixed, and fisheries (**Table 2**). The category of mixed source included anthropogenic litter of unclear origin (e.g., disposable diapers could be either from beach users or from land-based sources). Cigarette butts were also of uncertain origin because they can be discarded by users on beaches or in urban centers, and can reach the beaches through transportation by urban runoff (Armitage and
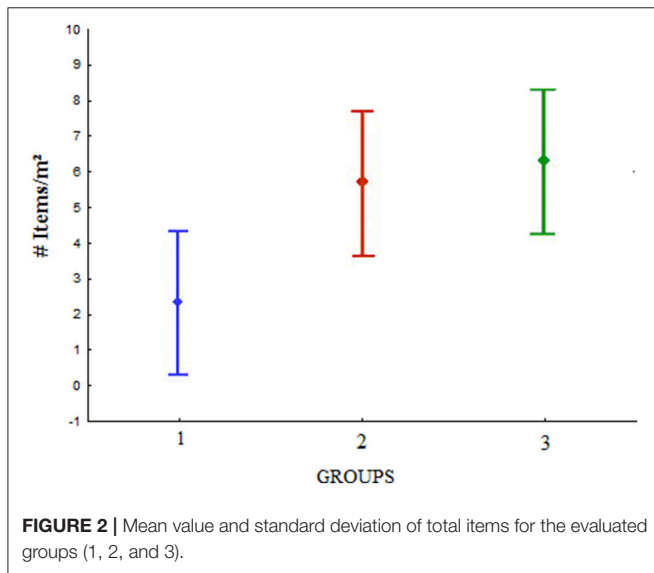
Rooseboom, 2000; Becherucci and Pon, 2014; Williams et al., 2016).

Fragments larger than 2 cm were sampled following the same sample design of the aforementioned categories ($100 \times 1\,\text{m}$ sections). For comparison, a random 10 m stretch of all sections was subsampled for all plastic fragments (0.5–2 cm).

An analysis of variance (ANOVA) was performed to determine the possible differences in the total number of litter items when compared between beach groups. The amount of beach-user related items was then compared between beaches

TABLE 2 | Classification of anthropogenic litter items according to the most likely source (Silva-Iñiguez and Fischer, 2003).

Sources	Items
Beach users	Straws, lollypop sticks, wooden skewers, water bottles, plates, cups, and cutlery made from plastic, food wrappers made from bio-orientated metalized polypropylene, hydrogen peroxide and sunscreen bottles, rubber sandals, cans and metal beverage lids, food scraps, food containers (such as take-away, and discardable plates and trays)
Land-based	Medicine packaging/containers, cotton swabs, bottles of cleaning products and personal hygiene products, food containers (such as margarine and cereal bags), cardboard.
Mixed	PET bottles, bottle rings/caps, plastic lids, disposable diapers, cigarette butts, condoms, maxipads, corks, plastic bags and wrappers, toys, lighters, pens, syringes and needles, Tetra Pak packages.
Fisheries	Nylon (monofilament lines, cables and ropes polyfilament) and tape, nets, styrofoam, fishing lines, glow/light sticks.

FIGURE 2 | Mean value and standard deviation of total items for the evaluated groups (1, 2, and 3).

in each group. The premises of normality and homoscedasticity were assumed. Where the ANOVA indicated a significant difference, a Tukey test followed by an HSD test was used to determine which beaches and items were significantly different at the 0.05 level of probability. These analyses were performed using STATISTICA software (Box et al., 2005; Silva-Cavalcanti et al., 2009).

RESULTS

A total of 12,815 items were found on the nine beaches within the three transects on each beach (one survey per beach), with densities (items/m^2) of 2.3, 5.7, and 6.3 for groups 1, 2, and 3, respectively. Although the same types of waste occurred on all beaches, the mean amount varied, especially among groups, and increased according to the level of urbanization when considering the total per group (16.3, 39.8, and 43.9% for groups 1, 2, and 3, respectively) (Figure 2).

However, when only the beaches were considered, the largest amounts of anthropogenic litter occurred at Porto de Galinhas

(group 2) and Bairro Novo (group 3) beaches, containing 25.4 and 21.4% of litter, respectively. The lowest values were found on Carneiros and Maracaípe beaches (group 1), with 3.3% and 3.1% of litter, respectively (Figure 3). Forte Orange and Bairro Novo presented the largest amounts of residues (60 and 49%, respectively) within their respective groups.

The most-represented items of anthropogenic litter in the evaluated samples were plastic, food/organic, and wood (wooden skewers), which constituted 57.3, 31.4, and 8.5% of the total samples, respectively. Other items accounted for less than 3% of the samples.

With respect to items composed of plastic, the majority were cigarette butts (45%); cigarette butts made up 26% of all anthropogenic litter samples collected.

## Possible Sources of Anthropogenic Litter

Items related to beach users were predominant for seven beaches, and were the majority for all the beaches in groups 2 and 3 (Table 3, Figure 4).

Porto de Galinhas showed a higher value of litter from beach users than that of the other beaches with higher levels of urbanization (Table 4). The results demonstrated that Porto de Galinhas beach was significantly different from the other beaches in group 2 ($p < 0.05$), as well as those in group 1 ($p < 0.05$). However, group 3 beaches ($p < 0.05$) were similar to Porto de Galinhas beach ($p > 0.05$) (Tables 3, 4).

In the category of beach-user related litter, 5 types of items (food scraps, wooden skewers, plastic straws, metallized plastic packaging, and lollypop sticks) made up 89.15% of all items of this source. The largest component was food scraps, which comprised 55.66% of all beach-user related litter (Figure 5).

Regarding the land-based source, Forte Orange beach obtained the highest values of items connected to this source, followed by Bairro Novo. Maracaípe and Porto de Galinhas had the lowest amounts. Within the mixed-source category, Porto de Galinhas and Bairro Novo beaches had the highest mean number of items, while Carneiros and Maracaípe beaches had the lowest amounts.

For the fisheries source category, Porto de Galinhas, Campas, and Maracaipe had the highest mean number of items. On the
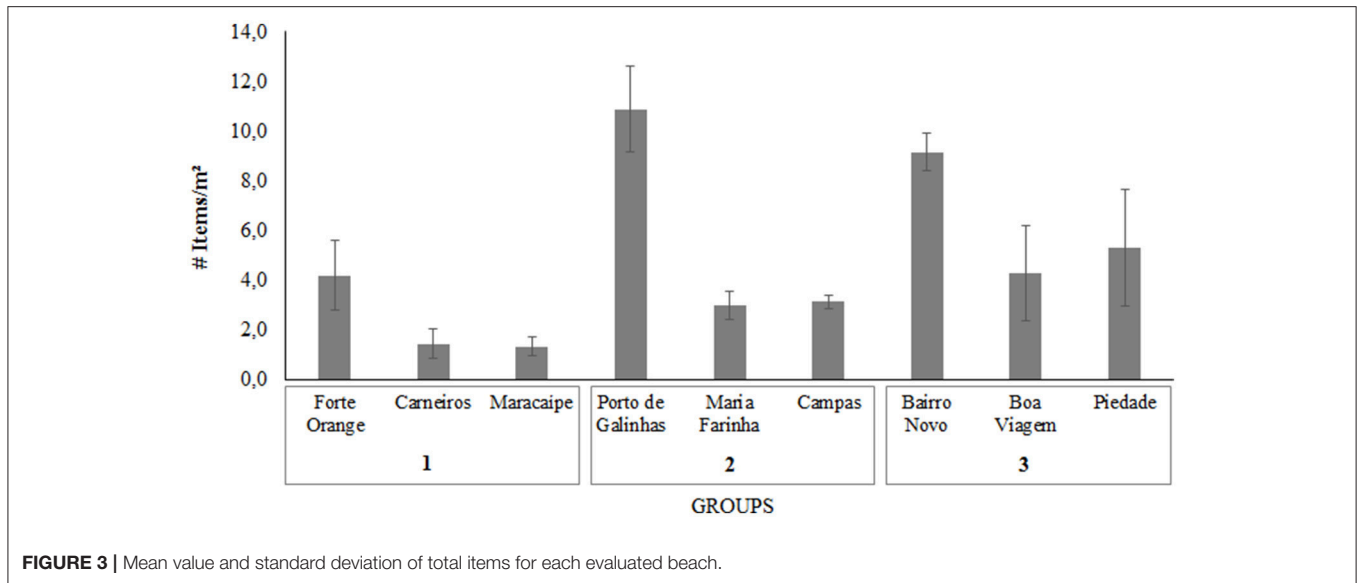
FIGURE 3 | Mean value and standard deviation of total items for each evaluated beach.

TABLE 3 | Mean value of items according to their possible source for all evaluated beaches.

		Sources			
		Beach users	**Land based**	**Mixed**	**Fisheries**
Group	Beach	$\bar{X} \pm$ S.D.	$\bar{X} \pm$ S.D.	$\bar{X} \pm$ S.D.	$\bar{X} \pm$ S.D.
1	Forte Orange	153.3 ± 69.5	36.7 ± 33.8	170.3 ± 49.6	9.3 ± 7.5
	Maracaípe	47.7 ± 15.2	0.7 ± 1.1	57.0 ± 20.8	12.0 ± 7.5
	Carneiros	78.7 ± 36.1	4.7 ± 1.5	33.3 ± 20.5	11.3 ± 6.7
2	Maria Farinha	164.7 ± 27.8	7.7 ± 1.1	101.7 ± 25.5	4.3 ± 1.5
	Porto de Galinhas	637.0 ± 147.0	2.7 ± 1.1	404.3 ± 57.5	16.3 ± 4.7
	Campas	172.0 ± 32.4	7.0 ± 2.6	95.7 ± 4.7	16.3 ± 8.5
3	Bairro Novo	572.3 ± 116.2	9.0 ± 4.6	287.7 ± 80.4	4.3 ± 2.0
	Boa Viagem	259.0 ± 110.0	5.3 ± 4.0	138.7 ± 75.7	0.0 ± 0.0
	Piedade	332.0 ± 175.1	7.0 ± 3.6	161.3 ± 63.5	1.7 ± 0.6

other hand, Boa Viagem and Piedade beaches had the lowest amounts (**Table 3**).

Evaluation of Plastic Fragments

Fragments larger than 2 cm corresponded to 4.47% of the total items, with 0.40, 0.20, and 0.46 items/m² for groups 1, 2, and 3, respectively. The largest amounts of fragments for both sizes were found in Forte Orange and Bairro Novo (**Figure 6**). A larger amount of fragments smaller than 2 cm occurred in all beaches; for this size fraction, the densities were 0.6, 0.5, and 0.76 items/m² for groups 1, 2, and 3, respectively, which were 1.5, 2.5, and 1.65 times higher, respectively, compared to those of fragments larger than 2 cm.

DISCUSSION

The level of urbanization had an influence on anthropogenic litter abundance, with the amount of anthropogenic litter increasing among the three beach groups. Leite et al. (2014) showed that there was a significant relationship between the proximity to an urban center and the contamination of the studied beaches. Hardesty et al. (2016) also found high debris densities near cities. Becherucci et al. (2017) evaluated the presence of litter on beaches at two locations on the Argentine coast, and noted that the largest proportion of litter occurred on beaches with greater use; according to the results, the amount and composition of the litter were reflections of the recreational use of the beaches. However, Porto de Galinhas presented the largest amount among all beaches, although it belonged to group 2 (medium level of urbanization). Two factors may have contributed to the large amount of anthropogenic litter in Porto de Galinhas. First, this beach is a scenic attraction and the main tourist destination in Pernambuco, with a larger concentration of users than the two other beaches with the same urbanization level, especially during the summer season (November to February). Second, the foreshore and backshore

FIGURE 4 | Mean value of items according to their possible source evaluated in the three beach groups.
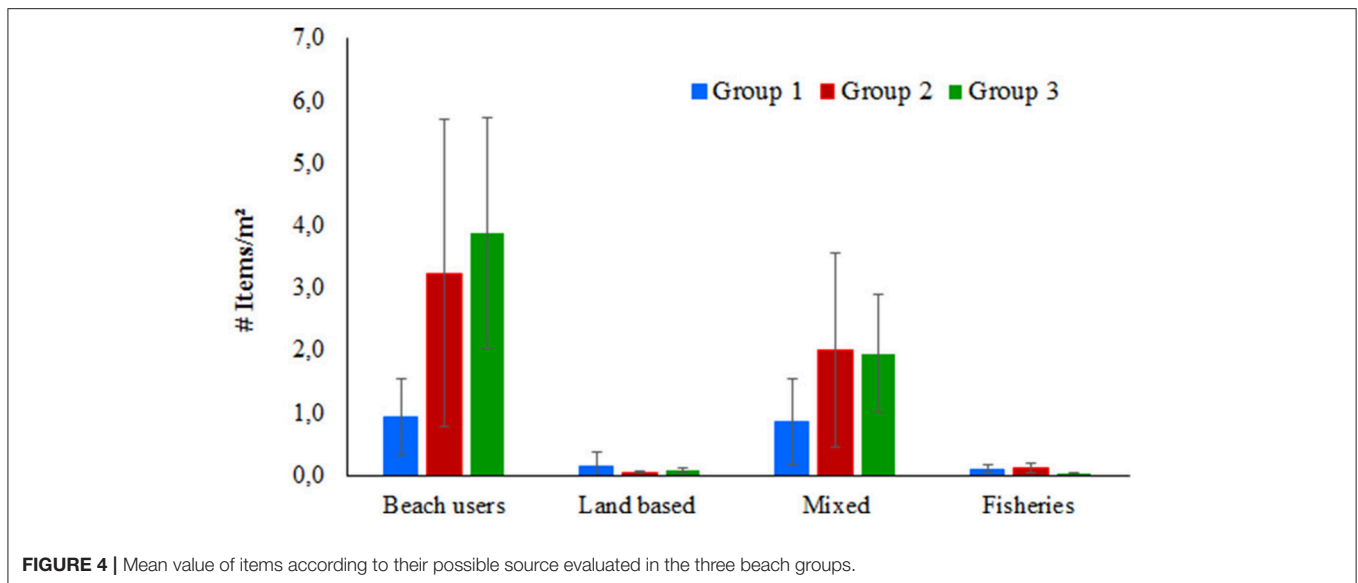
TABLE 4 | Summary of ANOVA analyses for the total number of items, development beach groups, and number of beach users.

Source of variation	Interaction	F-value
Total number of items x Groups	*	4.67
	1 2 3*	
	1* 2 3	
TOTAL OF USERS SOURCE ITEMS × GROUPS		
Group 1		69.887
	*	
	FO* <u>CAR MARAC</u>	
Group 2		
	*	
	PG* <u>MF CAM</u>	
Group 3	NS	

Tukey's HSD test post hoc comparison determined the differences in the total items on beaches in each group. FO is Forte beach, CAR is Carneiro beach, MARAC is Maracaípe beach, MF is Maria Farinha, PG is Porto deGalinhas, CAM is Campas beach, and NS is no significance.
*p≤0.05 NS-no significant. Underline means NO difference.

are reduced and are completely occupied by users, thereby favoring an accumulation of anthropogenic litter that is worsened by a poor city cleaning system.

Some factors may have contributed to the large amounts of litter in Forte Orange and Bairro Novo compared with the other beaches in their respective groups. Forte Orange is located on the mouth of an estuary, and thus receives a greater contribution of anthropogenic litter deposited by the tide and waves. When anthropogenic litter is improperly disposed of near watercourse environments, there is a high probability of anthropogenic litter being transported to coastal environments (Araújo and Costa, 2007b). Carneiros is a more isolated beach with access limitations due to the presence of a large number of private lands that prevent the entrance of vehicles and users. Maracaípe is a beach

without the protection of beach rocks and with waves that favor surf; thus, it is mainly used by surfers. Therefore, on both beaches (Carneiros and Maracaípe) the amount of users is lower, which reduces the amount of litter generated. Although Bairro Novo also has a high concentration of users, it is distinct from the other beaches in its group (within large cities) because it lacks an efficient system of street cleaning to remove the large amount of anthropogenic litter produced by its users. In contrast, the Boa Viagem and Piedade beaches rely on a system of street cleaning that removes most of the anthropogenic litter. For example, in Boa Viagem, 60 men clean the pavement and the sand strip three times per day by collecting litter (manually and by sweeping), which is then bagged and taken away. At night, sand cleaning is conducted by two tractors with sieves that remove litter up to 20 cm deep. Twenty tons of waste are removed from the beach daily (https://www.recife.pe.gov.br/pr/servicospublicos/emlurb/praiaviva.php).

In relation to the most likely sources of anthropogenic litter assessed, the confirmation that users are primarily responsible for the generation of anthropogenic litter may contribute to the development of actions and strategies aimed at reducing the problem, such as installing bins, installing distribution containers for anthropogenic litter collection, and implementing educational campaigns aimed at beach users.

Although food scraps (the most abundant items related to beach users) degrade faster than other types of anthropogenic litter, they are ideal substrates for the proliferation of pathogenic microorganisms (Zuza-Alves et al., 2016) and serve as a food source for many disease-spreading animals, such as insects, rats, and pigeons (Araújo et al., 2012).

Porto de Galinhas and Campas possess large expanses of sandstone reefs that have a high diversity of organisms (Ferreira et al., 2004; Frédou et al., 2009; Barradas et al., 2010). Thus, these beaches are extensively used for artisanal fishing, which may explain the greater number of items related to fisheries. The
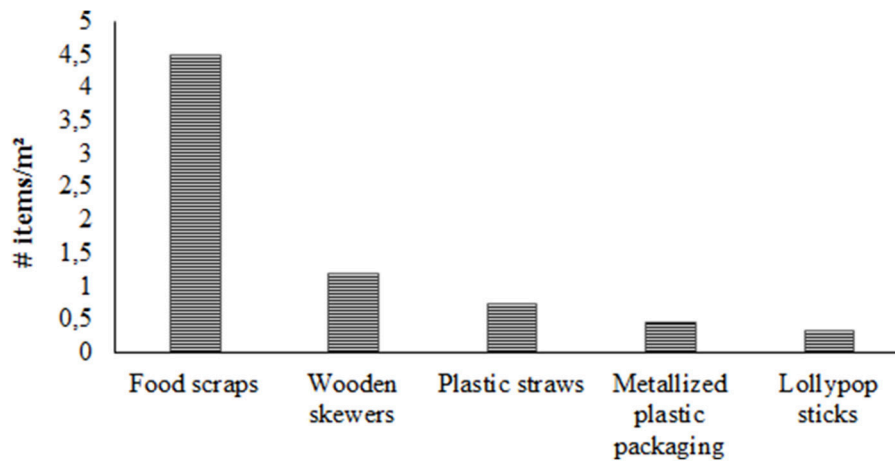
FIGURE 5 | Most abundant beach-user related litter items.
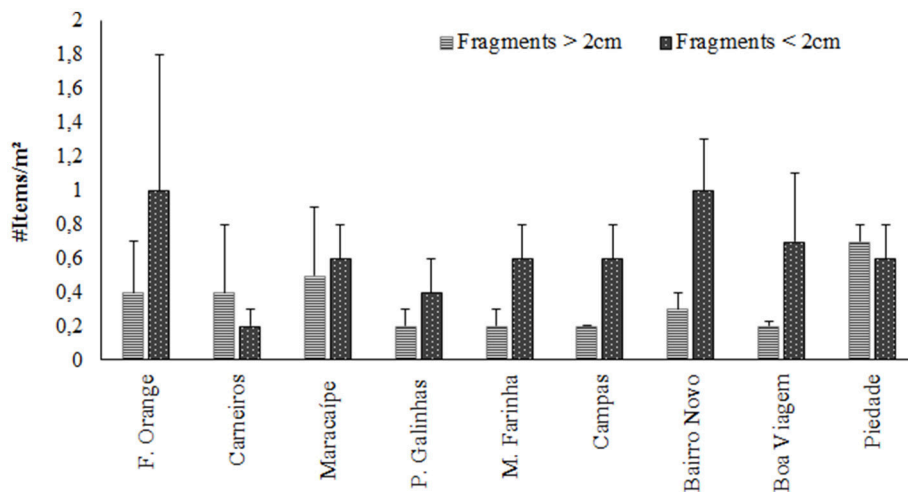

FIGURE 6 | Mean number and standard deviation of plastic fragments found on the strandline at the evaluated beaches.

presence of these residues in Maracaípe was probably due to its proximity to Porto de Galinhas.

For all beaches, the occurrence of residues unrelated to beach users was likely a consequence of the lack of effective anthropogenic litter management conducted by the municipalities.

With respect to the composition of the litter, plastic was the most abundant material. The high presence of plastic on all evaluated beaches is a pattern that occurs in numerous places in Brazil and other countries (UNEP, 2005, 2009, 2016; Araújo and Costa, 2007a; Ivar do Sul and Costa, 2007, 2013; Moore et al., 2011; Vieira et al., 2011).

Cigarette butts were also abundant, there by demonstrating that this item can be used as a marker of anthropogenic litter pollution level in highly urbanized and/or heavily used beaches. Santos et al. (2005) evaluated the relationship between beach users and anthropogenic litter and quantified the input of tourism-related anthropogenic litter by users with different socio-economic attributes in the southern Brazilian coast. Despite interviewing people that do not usually admit to littering on the beach, they observed that smokers usually leave their cigarette butts in the sand without much concern. Worldwide, the majority of sandy public beaches in tourist areas are also littered with cigarette butts (Novotny and Slaughter, 2014; Scisciolo et al., 2016; Becherucci et al., 2017). According to the International Coastal Cleanup program, which was conducted in 2016, 504,583 volunteers collected 13,840,398 items, of which 1,863,838 were cigarette butts (Ocean Conservancy, 2017)[1]. The small size and coloration of these items facilitate mixing in with the sand, thereby making it difficult for garbage disposal workers to gather

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[1]Available online at: http://www.oceanconservancy.org/our-work/international-coastal-cleanup/2016-ocean-trash-index.html (Accessed November 13, 2017).

them, which leads to adverse effects on the environment (Ariza et al., 2008; Ariza and Leatherman, 2012; Leite et al., 2014).

The presence of small fragments (<2 cm) in large quantities demonstrated that larger items undergo fragmentation into smaller pieces. Items smaller than 2 cm can still suffer successive breakage and become increasingly smaller items.This fact is potentially impactful, mainly because the small size favors a nearly imperceptible accumulation in the environment; consequently, these fragments persist in the environment for indefinite periods. The size of the residue is directly related to its hazard to animals; the smaller the fragments are, the greater the risk of accidental ingestion or confusing them as food (Galloway, 2015; Lusher et al., 2015).

When ingested, fragments can cause obstruction in the digestive system of the animal or give it a feeling of satiety, which will then reduce its search for food and eventually cause malnutrition and death. There are numerous reports of animals that contained plastic fragments or whole items inside their digestive tracts (Bugoni et al., 2001; Copello and Quintana, 2003; Ivar do Sul and Costa, 2007; Moore, 2008; Possatto et al., 2011; Galloway, 2015; Lönnstedt and Eklöv, 2016; Vendel et al., 2017).

Beach cleaning is costly because it is time-consuming as well as economically expensive. According to Mouat et al. (2010), municipalities throughout the northeast Atlantic region continue to face high costs associated with the removal of anthropogenic litter. UK municipalities spend approximately €18 million each year removing anthropogenic litter, which represents a 37% increase in cost over the past 10 years. Similarly, removing anthropogenic litter costs municipalities in the Netherlands and Belgium approximately €10.4 million per year. Clearly, costs increase with sample area. Therefore, the collection effort must be planned with the goal of saving both economic and human resources.

Planning should establish the minimum effort required to collect data in order to produce satisfactory results, so that the methodology can be repeated with clear and economical ways to manage research activity as well as other research. The choice of representative items (such as cigarette butts) to determine the level of beach pollution can reduce the sampling effort by enabling diagnosis for more extensive areas.

The human component, including attitude toward the environment, is critical for effective anthropogenic litter management. Public awareness and encouraging changes in attitudes related to anthropogenic litter management are essential components in efforts to mitigate the presence of anthropogenic litter in marine and coastal environments.

AUTHOR CONTRIBUTIONS

FUNDING

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