Waste Management 108 (2020) 13–20

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Marine debris on a tropical coastline: Abundance, predominant sources and fate in a region with multiple activities (Fortaleza, Ceará, northeastern Brazil)

Rivelino M. Cavalcante [a,*], Lidriana S. Pinheiro [b], Carlos E.P. Teixeira [c], Barbara P. Paiva [c,d], Gabrielle M. Fernandes [a,d], Daysiane B. Brandão [d], Felipe F. Frota [d], Francisco J.N.S. Filho [d], Carlos A.F. Schettini [e]

[a] Laboratory for Assessment of Organic Contaminants-LACOr, Institute of Marine Sciences, Federal University of Ceará, Fortaleza, Ceará 60165-081, Brazil
[b] Geology and Oceanography Laboratory-LOG, Institute of Marine Sciences, Federal University of Ceará, Fortaleza, Ceará 60165-081, Brazil
[c] Physical Oceanography Laboratory-LOF, Institute of Marine Sciences, Federal University of Ceará, Fortaleza, Ceará 60165-081, Brazil
[d] Undergraduate Course in Oceanography, Institute of Marine Sciences, Federal University of Ceará, Fortaleza, Ceará 60165-081, Brazil
[e] Federal University of Rio Grande, Rio Grande do Sul, Brazil

ARTICLE INFO

Article history:
Received 2 October 2019
Revised 10 March 2020
Accepted 14 April 2020
Available online 22 April 2020

Keywords:
Litter
Accumulation zone
Floating marine debris
Sink

ABSTRACT

The aim of the present study was to perform the first assessment of the abundance and classification of marine debris as well as determine the sources, transport and fate of this debris on an urbanized coast with multiple human activities. More than 80% of the marine debris was composed of synthetic materials. The beached marine debris was classified according to size. Meso-debris accounted for the highest portion of contamination (55%), followed by macro-debris (25.1%) and small debris (19.9%). Contamination by debris, such as cotton swabs (31%) and lollipop sticks (36.8%) accounted for the largest portion of the small debris class. Human recreational activities were the predominant source of debris, followed by navigation/fishing activities, domestic activities and industrial/port activities. The assessment of the predominance of human activities and the results of the model revealed a larger contribution of debris from recreational activities on nearby beaches on the small to larger scale and that rivers exert less of an influence due to the fact that they do not flow the entire year.

1. Introduction

Coastline contamination by solid waste is a global concern and has become a major environmental problem with the increase in the population of large cities (Ariza et al., 2008; Gall and Thompson, 2015). Due to the diversity of chemical compositions, when different types of solid waste are discharged into the environment, their constituents can be also released, which are often persistent pollutants that can be harmful to living organisms (Geyer et al., 2017).

There is an inverse correlation between public policies and studies conducted on the fate and impact of litter in the environment. For example, developed countries (e.g., North America and Europe) have strong solid waste policies and much more studies compared to countries that have weak public policies and thus contribute much more litter to the environment (e.g., South America and Africa) (Ivar do Sul and Costa, 2014; Gall and Thompson, 2015; Jambeck et al., 2015). Although the Brazilian coastline is more than 8500 km in length and is home to 70% of the population, scarce studies in the last decade have indicated that litter on the Brazilian coastline is related to inadequate disposal, a lack of collection along the banks of rivers and estuaries, the influence of ocean currents and tourist activities and the lack of public policies in urban areas (Costa et al., 2010; Ivar do Sul and Costa, 2014; Petersen et al., 2016).

According to Coe and Rogers (1997), any solid waste material that enters the marine environment from any source is defined as marine debris and can be classified according to its origin (e.g., coastal users, ships and offshore installations) (Hinojosa and Thiel, 2009). The dynamics of marine debris are uncertain, as some objects sink immediately to the ocean floor, while others remain afloat for unknown periods (Hinojosa and Thiel, 2009; Ruiz-Orejón et al., 2018). Marine debris is generally not found at its launch site, but rather far from the source. Thus, most studies

* Corresponding author at: Institute of Marine Sciences, Federal University of Ceará, Av. Abolição 3207, CEP 60165-081 Fortaleza, CE, Brazil.

E-mail address: rivelino@ufc.br (R.M. Cavalcante).

https://doi.org/10.1016/j.wasman.2020.04.026
0956-053X/

address solid waste and litter that wash up on beaches (Santos et al., 2005a, 2005b; Araújo and Costa, 2006; Zhou et al., 2016). Investigations of marine debris are indispensable to understanding the processes of input, transport and fate (accumulation zones). Such studies can assist in solving marine problems, highlight the considerable impact on marine life and demonstrate the failure of solid waste management. Therefore, the aim of the present study is to determine the amount of debris, categorize it by size and type of material, determine associated human activities and perform modeling of the input, transport and fate of the debris. This is the first survey of marine debris on the coast of the state of Ceará, Brazil and may be helpful to improving waste and litter management practices in coastal regions.

2. Material and methods

2.1. Study area

The city of Fortaleza is located on the Atlantic coast of northeastern Brazil (Fig. 1). The climate is tropical and characterized by rainy (February to July) and dry (August to December) periods (Gusev et al., 2004). Fortaleza is the fourth most important city in Brazil, has heavy traffic (one million vehicles) and more that 2.5 million inhabitants distributed over an area of 313 km^2. The main anthropogenic impacts on the coastline are port activities, tourist activities, urban and industrial wastewater as well as activities related to oil transport, discharge and refinement (Cavalcante et al., 2010). No previous study has addressed marine debris in this region, although some studies have shown pollution by semi-volatile and volatile hydrocarbons (Cavalcante et al., 2010).

Sampling was performed on Mansa Beach, which emerged naturally after the construction of the jetty for the Mucuripe Port. The beach is located within the port area and has no public access. The region is under the influence of two small rivers that pass through highly populated areas: Coco River and Maceio River, located respectively to the east and west of Mansa Beach. Beira Mar beach is another potential source of solid waste due to tourist and leisure activities and also receives water from urban fluvial systems, which transport solid material due to inefficient public trash collection.

2.2. Sampling and pre-treatment

There are numerous methods for sampling micro- and macro-debris on beaches and the method of choice is based on the objectives of the work (Velander and Mocogni, 1998). After a careful evaluation of the study area, the most suitable sampling method was the establishment of sectors measuring 30 × 35 m from the low-water line to the frontal dunes (Fig. 1), as suggested by Velander and Mocogni (1999) and Araújo et al. (2006).

After the separation of the sectors, debris was collected and placed in plastic bags. All debris collected since July 2009 was transported to the Marine Sciences Institute (LABOMAR) for further evaluation. After a brief wash using water, the items were photographed, divided into categories (size classification and typology) and weighed. Percentages were calculated in terms of size and type of material, following recommendations found in the literature (Debrot et al., 1999; Araújo et al., 2006).

The following size classification was used: small debris (1–40 mm in length); meso-debris (40.01 to 200 mm in length) and macro-debris (above 200.01 mm in length). The small debris category included a subclass denominated large microplastics (1–5 mm), as suggested by Monitoring Guidance for Marine Litter in European Seas (Van Cauwenberghe et al., 2015; Andrady, 2017). Virgin plastic pellets (characterized as large microplastics) were analyzed semi-qualitatively due to the sampling method used (collected by five people with the naked eye) in each sector.

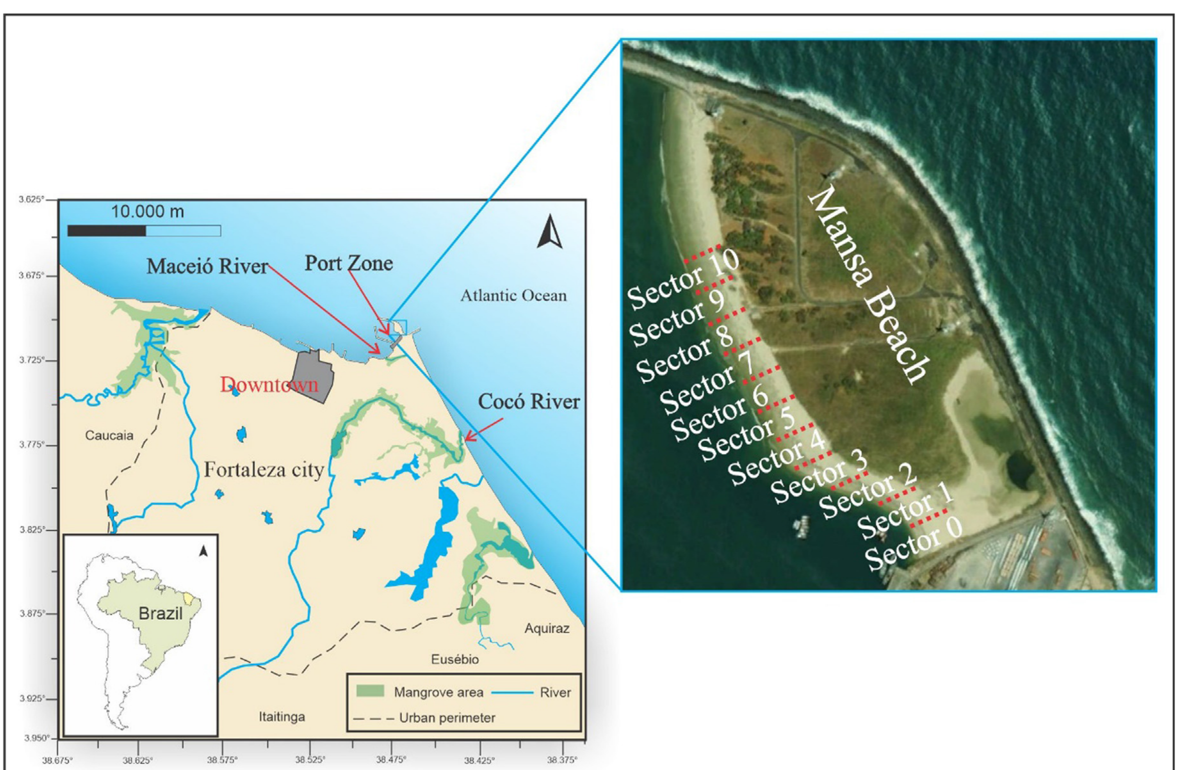

Fig. 1. Sampling area with sector scheme.

2.3. Model and data analysis

To gain a better understanding of the possible sources of marine debris, the circulation in the region was simulated using the Delft3D model. The area considered was approximately 40 km along the coast and 30 km offshore. This area contains the entire inner shelf adjacent to the city of Fortaleza and its main discharge regions. Simulations were performed for the periods of February to April (representing the wet season), with weak northwestward winds, and July to September (representing the dry season), with strong westward winds. Details on the configuration and validation of the model are presented in the supplementary material.

3. Results

3.1. Abundance, density and composition of marine debris

The debris concentrations on the coast of the city of Fortaleza are summarized in Table 1.

Abundance was 7,510 items in the study area, with a computed total of around 71.9 kg of debris. Abundance was highly variable among the size categories: 41 to 550 items of small debris, three to 2059 items of meso-debris and 18 to 666 items of macro-debris per sector, totaling a density of 0.8 to 15.5 g/m^2 and 0.21 to 1.15 items/m^2 (Fig. 2).

In percentage terms, meso-debris accounted for the highest proportion of contamination (55%), followed by macro-debris (25.1%) and small debris (19.9%) (Table 1S, Supplementary Material). Considering type of debris, contamination ranged from 31% for cotton swabs to 36.8% for plastic lollipop sticks in the small debris class, from 0.1% for diverse cloths to 49.9% for plastics in the meso-debris class and from 1% for metals to 35.3% for polystyrene foam in the macro-debris class (Fig. 2). Virgin plastic pellets (large microplastic subclass) accounted for 2.7% of small debris and 0.5% of overall abundance (Table 1S, Supplementary Material).

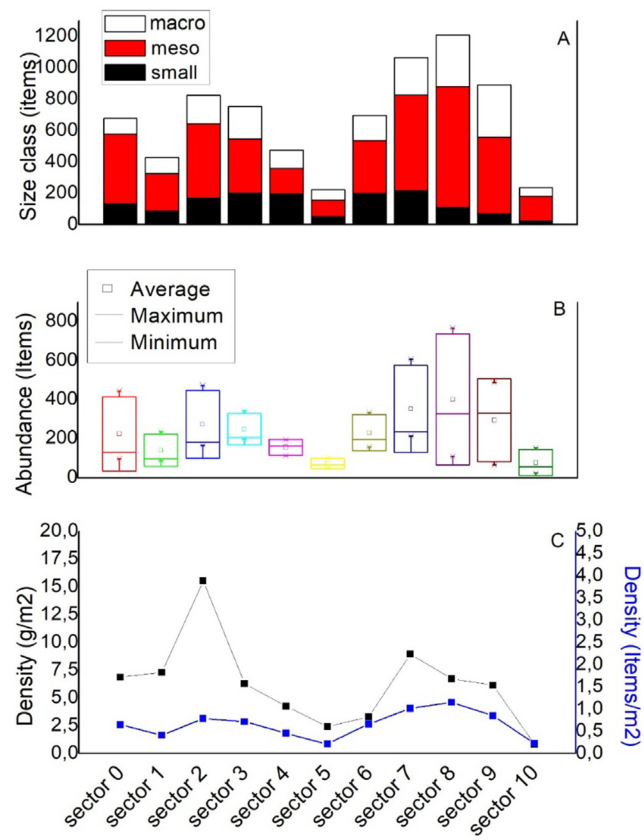

Fig. 2. Distribution of marine debris by sector: (A) size class, (B) abundance and (C) density.

Distribution was quite diversified, but 82.6% of marine debris was predominately synthetic materials (e.g., nylon, polystyrene

Table 1
Concentration of BMD (sum and percentage of type and class).

	Sectors													
	0	1	2	3	4	5	6	7	8	9	10	**Sum**	**Type (%)**	**Class (%)**
Small-debris														
Cotton swab	45	17	54	57	40	19	61	65	53	24	5	440	29.5	5.9
Cigarette butt	17	14	44	58	92	18	69	91	27	16	17	463	31.0	6.2
Lollipop holder (plastic)	70	58	69	85	64	15	69	59	30	28	3	550	36.8	7.3
Virgin plastic pellets	5	3	6	5	3	7	3	6	3	–	–	41	2.7	0.5
Total	137	92	173	205	199	59	202	221	113	68	25	**1494**		**19.9**
Meso-debris														
Plastic material (diverse)	302	190	321	210	104	80	165	263	240	155	29	2059	49.9	27.4
Glass container	0	4	0	1	1	1	2	5	1	1	0	16	0.4	0.2
Cloth (diverse)	1	0	0	0	1	0	0	0	0	1	0	3	0.1	0.0
Nylon	4	2	7	7	2	2	4	4	14	1	0	47	1.1	0.6
Polystyrene foam (diverse)	3	1	31	47	39	1	135	270	472	298	111	1408	34.1	18.7
Aluminum	8	0	1	0	0	0	0	0	0	0	0	9	0.2	0.1
Others	128	41	115	79	16	20	30	69	43	33	14	588	14.2	7.8
Total	446	238	475	344	163	104	336	611	770	489	154	**4130**		**55.0**
Macro-debris														
Plastic material (diverse)	57	51	89	114	44	44	55	56	65	51	6	632	33.5	8.4
Rubber and leather	24	7	23	16	3	5	7	17	13	15	2	132	7.0	1.8
Polystyrene foam (diverse)	2	7	15	41	30	8	51	104	168	205	35	666	35.3	8.9
Polyurethane	0	0	4	2	2	0	2	6	11	4	1	32	1.7	0.4
Metals	1	2	7	0	2	2	2	1	0	1	0	18	1.0	0.2
Fishing material	12	7	18	15	4	3	23	28	11	20	6	147	7.8	2.0
Glass	0	6	2	3	4	0	0	0	5	6	0	26	1.4	0.3
Paper	4	4	8	2	5	1	1	4	6	3	1	39	2.1	0.5
Others	0	16	16	15	21	3	19	22	49	27	6	194	10.3	2.6
Total	100	100	182	208	115	66	160	238	328	332	57	**1886**		**25.1**
Global abundance (items)	***683***	***430***	***830***	***757***	***477***	***229***	***698***	***1070***	***1211***	***889***	***236***	***7510***		***100.0***

foam and diverse plastics) (Table 1S, Supplementary Material). This is similar to findings described in other marine debris studies, which show that plastics contribute most to the contamination of the environment (Zhou et al., 2016). The second predominant class was cigarette butts (6.2%), followed by wood (2.6%) and metal, glass and others (Fig. 3). Among the "others", the most common were food containers, disposable cups, bottles for house cleaning products, plastic seals, personal hygiene bottles as well as a larger number of cotton swabs and plastic straws (Fig. 3). Unusual findings included virgin plastic pellets of an unknown chemical class as well as cotton swabs and lollipop sticks, which are uncommon in studies on marine debris (Fig. 3).

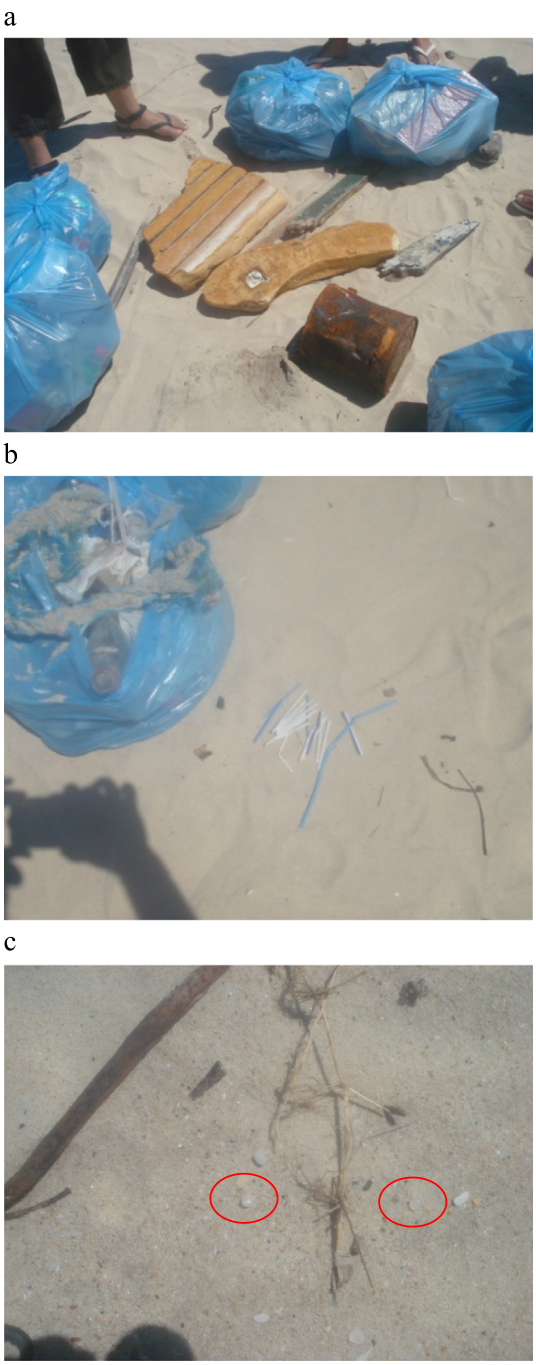

Fig. 3. Predominant material: (a) polystyrene foam and metal (sector 2); (b) cotton swabs, plastic straws and lollipop sticks (sector 7); (c) virgin plastic pellets (sector 5). Source: Authors.

3.2. Predominance of human activities

The four main sources of marine and coastal litter are coastal recreational activities, tourism-related activities, navigation/fishing and sewage (Sheavly and Register, 2007; Hinojosa and Thiel, 2009). Thus, the typology of litter found in the accumulation zone can give an indication of the human activities that contributed to the contamination (Araújo et al., 2006; Hinojosa and Thiel, 2009; Zhou et al., 2016). For such, we used the absolute frequency of the type of small debris (Pareto's principle), as this class is transported longer distances and arrives at accumulation zones more efficiently than another classes of marine debris and can therefore be used for the assignment of anthropogenic sources (Ryan, 2015; Becheruccia et al., 2017) (Fig. 5 and Table 2S, Supplementary Material). The Pareto diagram shows that the predominant source was a mixture of human activities (not easily defined) (Fig. 5). However, based on the remaining results, the second predominant source was recreational activities, followed by navigation/fishing activities, domestic activities and, to a lesser extent, industrial/port activities (Fig. 5).

3.3. Results of model

The time-averaged residual currents for the periods of February to April (Fig. 4a) and July to September (Fig. 4b) show that the jetty leads to shear in the along-shore currents, forcing a local clockwise eddy westward of Mansa Beach. This eddy leads to an 8 cm/s residual circulation that is half of the sub-tidal currents and opposite to the wind direction.

Currents have the same directions throughout the year but vary in strength. Westward currents are present from July to September (Fig. 4b) in shallow regions close to the coast westward of Mansa Beach, when winds are stronger in the region (average wind velocity: 5 m/s). These same currents are very weak from February to April (Fig. 4a), when winds are also weaker (average wind velocity: 2 m/s). The eddy is also stronger from July to September due to the stronger currents.

Northwestward currents are present in the region eastward of Mansa Beach, driven by winds and following the direction of the coast. Due to the direction of the winds, these currents are stronger from February to April compared to the period from July to September. This is the opposite of what occurs westward of Mansa Beach.

4. Discussion and conclusion

4.1. Levels, classification and typology of BMD

The debris distribution patterns found on Mansa Beach are different from those described in other studies. Solid waste or marine debris found on tourist beaches is usually derived from domestic activities and differs in quantity between urbanized and non-urbanized (natural) beaches (Araújo et al., 2007a; Ariza et al., 2008). On non-urbanized tourist beaches in northeast Brazil, litter is mainly composed of food containers, disposable plates, cups and cutlery, bottles for house cleaning products, personal hygiene bottles, fishing equipment and sewage; moreover, the composition is generally the same, with differences only in quantity (Araújo and Costa, 2006; Araújo and Costa, 2007a; Araújo and Costa 2007b). On urbanized tourist beaches, the amount of debris is much higher, especially in summer, despite daily public cleaning. Moreover, the composition of trash is more diversified, but exhibits the same pattern of household material due to the proximity to the residences of users and supermarkets (Ariza et al., 2008).

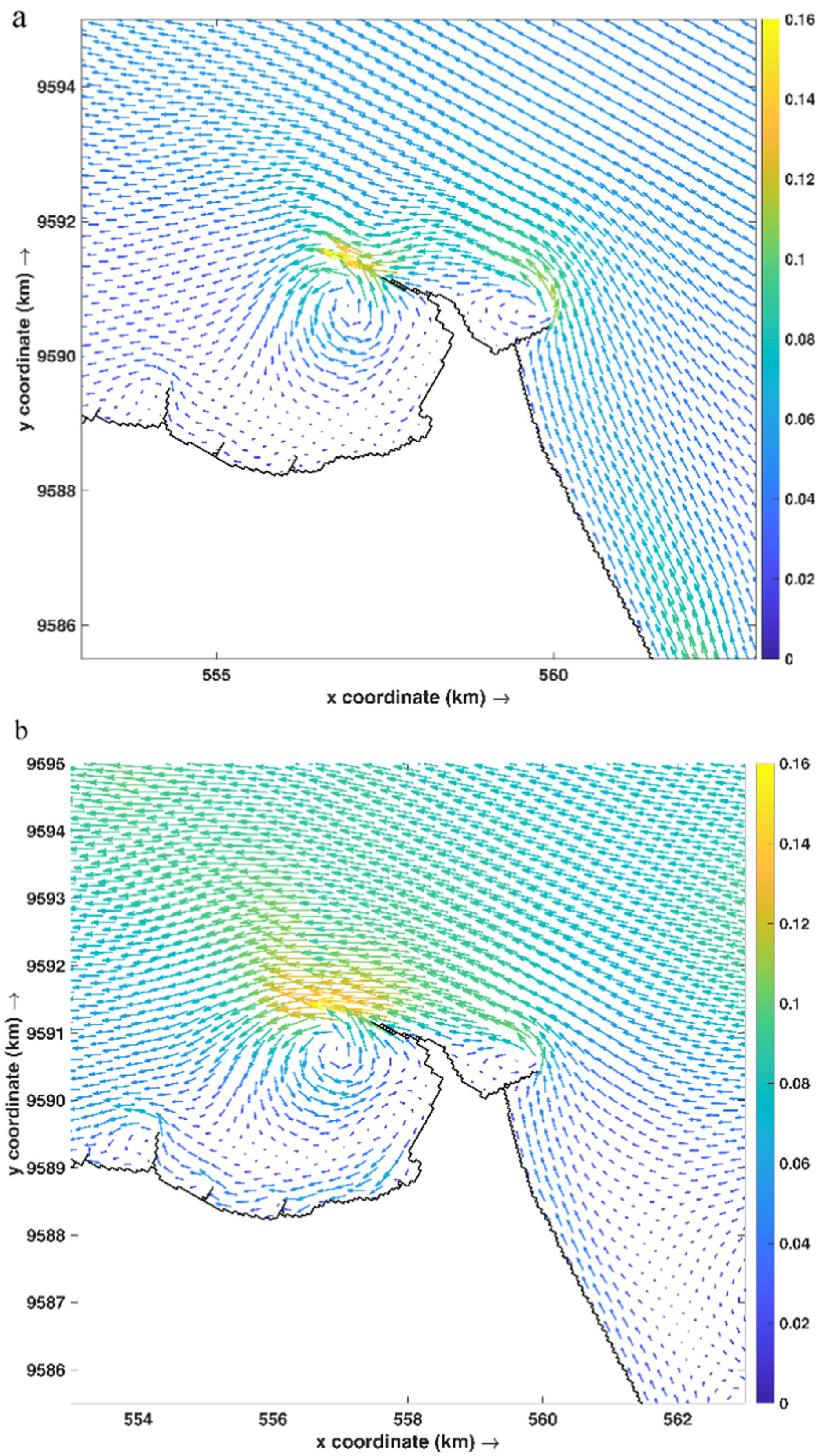

Fig. 4. Depth-averaged residual circulation for region. Results are averaged for (a) February to April and (b) July to September. Colors denote magnitude of currents in m/s. A clockwise eddy is present in both periods and is stronger from July to September. Currents have the same directions throughout the year but vary in strength. Westward currents are stronger in July to September due to stronger winds.

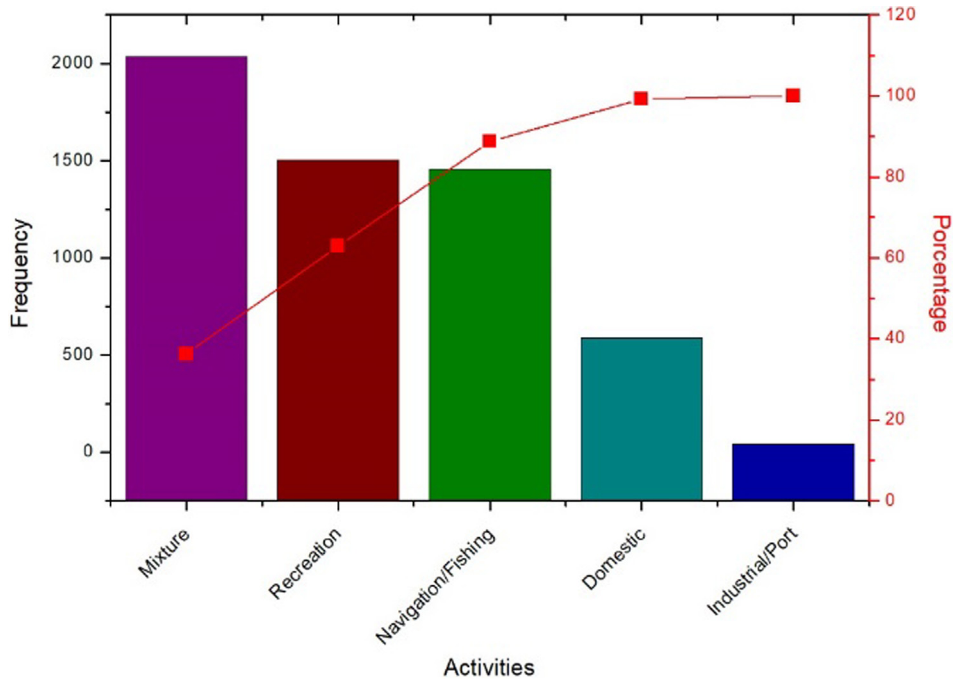

Fig. 5. Pareto diagram of small debris class.

The fact that the material found on Mansa Beach does not resemble that found for tourist activities is explained by the fact that the beach is not open to the public and visitors are not common at any time of the year. Density (g/m^2 and $items/m^2$) (Fig. 2) also differed compared to tourist beaches, with much lower values compared to those found on urbanized and non-urbanized beaches (Araújo and Costa, 2007a; Araújo and Costa, 2007b; Ariza et al., 2008) and the same magnitude as that found at isolated sites on oceans, such as fjords and islands (Coe and Rogers, 1997; Williams et al., 2005; Hinojosa and Thiel, 2009; Petersen et al., 2016).

Therefore, the debris must have been brought to the location through different sources, followed by deposition, thus being characterized more as transported and beached marine debris. The literature generally classifies marine debris as beached (BMD), floating (FMD) or submerged (SMD) (Hinojosa and Thiel, 2009; Rosevelt et al., 2013; Zhou et al., 2016). According to Zhou et al. (2016), BMD has no defined standards and it has ability to float and be transported over long distances. Although not all plastics float, as many have a higher density than seawater (Schwarz et al., 2019), BMD is mainly composed of low-density plastics that can be dispersed for long distances by both winds and surface ocean currents (Zhou et al., 2016), which may be the reason why more than 80% of the material found was composed of synthetic material, particularly plastics of different sizes and classes (Fig. 3). Much of the debris was composed of cotton swabs, plastic straws, plastic lollipop sticks, cigarette butts and virgin plastic pellets, which float easily and can therefore be transported long distances (Hinojosa and Thiel, 2009; Ivar do Sul and Costa, 2007; Ivar do Sul et al., 2009).

Due to the ingestion of marine debris by animals, small (especially micro and nano) debris and meso-debris have recently received considerable attention (Li et al., 2016). There were no significant differences in the type and abundance of the meso-debris found; cotton swabs, plastic straws and cigarette butts were predominant, as described in other studies on BMD (Hinojosa and Thiel, 2009; Ivar do Sul et al., 2009; Zhou et al., 2016; Loulad et al., 2017), except for lollipop sticks, which are not commonly reported. Cotton swabs are mainly used for personal hygiene purposes and therefore come from domestic activities. Lollipop sticks are likely used by people during recreational activities. The presence of both materials is probably due to inadequate disposal and failure with regards to municipal solid waste management. Plastic straws are common on Brazilian beaches and most likely linked to recreation, considering the more than one million users per month on the neighboring Futuro and Mucuripe Beaches. Ivar do Sul and Costa (2007) report that beach users leave drinking straws and cups, which represent 28% of the total debris. Moreover, 25% of interviewees in another study admitted to having littered on the beach and attributed the generation of debris to beach users (Santos et al., 2004, 2005a, 2005b). Cigarettes are commonly smoked during the diverse activities, especially related to leisure and recreation, and cigarette butts are therefore considered a ubiquitous type of debris found in the environment (Hinojosa and Thiel, 2009; Becheruccia et al., 2017). According to Ivar do Sul and Costa (2007), cigarettes butts are not effectively removed by cleaning services and remain on the beach. Moreover, the predominance of these items as marine debris is partially due to their high persistence and low density (Becheruccia et al., 2017).

Virgin plastics pellets are used as raw materials for the fabrication of plastic products and enter the environment via "escape" during transportation, manufacturing, storage or use (Van Cauwenberghe et al., 2015; Li et al., 2016; Andrady, 2017). Virgin plastics pellets made up only 0.5% of the total items in the present study, although this figure is likely underestimated due the sampling method. Indeed, this item was a surprise, as it is more common to find pellets using a sampling method that is adequate for microplastics (see Fig. 3c). The plastic production and transformation industry is one of the main manufacturing sectors of the Brazilian economy and the state of Ceará ranks sixth and tenth in the recycling and production of processed plastics, respectively (ABIPLAST - http://www.abiplast.org.br/publicacoes/). It is estimated that more than 30 companies are found in the state, especially to meet the demands of the food industry, and there is also an unknown number of unregistered locations spread throughout the state. This material enters through the port. It likely "escaped" and was transported to the study area. Virgin plastic pellets found on Fernando de Noronha Island are transported by surface currents from the mainland, since there is no plastic industry on the island (Ivar do Sul et al., 2009). Although there is no consensus in the literature, according to Turner and Holmes (2011), the color of a plastic pellet reveals how long it has been in the environment, as darker pellets (e.g., brown and amber) are more photo-oxidized and have undergone different degrees of weathering. Therefore, the plastic pellets found on Mansa Beach were probably transported from a nearby place, since their color was the same as that of virgin plastic material (see Fig. 3).

4.2. Predominance of human activities, input and fate of BMD

Recreational activities and navigation/fishing activities were also the main sources of trash on beaches in coastal areas of China and attributed to the predominance southeasterly winds during the wet season, which results in increased accumulations (Zhou et al., 2016). On the beaches of the southwestern Atlantic (Argentina), recreational activities exert a significantly greater influence on more popular beaches (e.g., those of Mar del Plata) than fishing activities, whereas fishing activities are the predominant source of marine litter on less used beaches (Becheruccia et al., 2017). "Shipping waste" from navigation activities was considered the main source of litter on non-urbanized beaches in northeast Brazilian, surpassing even classic sources, such as recreational and tourism activities (Santos et al., 2005a, 2005b). Sea-based aquaculture activities were predominant in southern Chile (Hinojosa and Thiel, 2009).

Since Mansa Beach is not open to the public, local hydrodynamic circulation and winds are (Araújo and Costa, 2007a) the main transporters of debris to the beach. Hydrodynamic circulation makes Mansa Beach an accumulation zone for BMD, which enters the region through two local river inputs, port activities and recreational activities on two nearby, highly visited beaches. Circulation eastward of Mansa Beach brings marine debris that enters the ocean from the Cocó River and Futuro Beach near the study area (Fig. 4a and b). Moreover, the local eddy brings marine debris from Mucuripe Beach and the Maceio River (both located westward) to Mansa Beach (Fig. 4a and b). This eddy may also transport marine debris from the port to the area, making Mansa Beach an accumulation point for debris related to navigation/fishing activities.

The assessment of the predominance of human activities and the results of the model results revealed a larger contribution of debris from recreational activities on the two beaches near the study area. This is plausible, as such activities are intense, with the frequent presence of both locals and tourists throughout the year. The model results also show geographically that the input is on the small, medium and larger scales. Although navigation/fishing activities are near the study area, there is a greater probability that debris from these activities is dispersed more efficiently. Moreover, the port zone and Maceio River, which are near the study area, exerted less influence compared to industrial/port and domestic activities, as the port zone has a solid waste policy and the river does not flow the entire year.

Acknowledgments

This paper is in commemoration of the ten years of the Oceanography Course of the Federal University of Ceará-UFC. Congratulations to the professors, technicians and students for their efforts in understanding and defending the interests of the ocean and its margins. This research was supported by the PRONEN FUNCAP/CAPES Research grant. This study is part of the project "I-plastics: Dispersion and impacts of micro- and nano-plastics in the tropical and temperate oceans: from regional land-ocean interface to open ocean". R.M. Cavalcante, L.S. Pinheiro and C.A.F Schettini wishes to thank CNPq (Brazilian National Council for Scientific and Technological Development) for PQ-2 Grant.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2020.04.026.

References

Andrady, A.L., 2017. The plastic in microplastics: a review. Mar. Pollut. Bull. 119(1), 12–22. 10.1016/j.marpolbul.2017.01.082.
Araújo, M.C.B., Costa, M., 2006. Municipal services on tourist beaches: costs and benefits of solid wastes collection. J. Coast. Res. 22(5), 1070–1075. 10.2112/03-0069.1.
Araújo, M.C.B., Santos, P.J.P., Costa, M., 2006. Ideal width of transects for monitoring source-related categories of plastics on beaches. Mar. Pollut. Bull. 52 (2006), 957–961. https://doi.org/10.1016/j.marpolbul.2006.04.008.
Araújo, M.C.B., Costa, M., 2007a. An analysis of the riverine contribution to the solid wastes contamination of an isolated beach at the Brazilian Northeast. Manage. Environ. Qual.: Int. J. 18(1), 6–12. 10.1108/14777830710717677.
Araújo, M.C.B., Costa, M., 2007b. Visual diagnosis of solid waste contamination of a tourist beach: Pernambuco, Brazil. Waste Manage. 27(6), 833–839. 10.1016/j.wasman.2006.04.018.
Ariza, E., Jiménez, J.A., Sardá, R., 2008. Seasonal evolution of beach waste and litter during the bathing season on the Catalan coast. Waste Manage. 28(12), 2604–2613. 10.1016/j.wasman.2007.11.012.
Becheruccia, M.E., Rosenthal, A.F., Pon, J.P.S., 2017. Marine debris in beaches of the Southwestern Atlantic: an assessment of their abundance and mass at different spatial scales in northern coastal Argentina. Mar. Pollut. Bull. 119(1), 299–306 10.1016/j.marpolbul.2017.04.030.
Cavalcante, R.M., Andrade, M.V.F., Oliveira, L.D.M., Marins, R.V., 2010. Development of a headspace-gas chromatography (HS-GC-PID-FID) method for the determination of VOCs in environmental aqueous matrices: Optimization, verification and elimination of matrix effect and VOC distribution on the Fortaleza Coast, Brazil. Microchemical. J. 96(2), 337–343. 10.1016/j.microc.2010.05.014.
Coe, J.M., Rogers, D. (Eds.), 1997. Marine Debris: Sources, Impacts and Solutions. Springer, New York.
Costa, M.F., Ivar do Sul, J.A., Santos-Cavalcanti, J.S., Araújo, M.C.B., Spengler, A., Tourinho, T.S., 2010. Small and microplastics on the strandline: snapshot of a Brazilian beach. Environ. Monit. Assess. 168, 299–304.
Debrot, A.O., Tiel, A.B., Bradshaw, J.E, 1999. Beach Debris in Curaçao. Mar. Pollut. Bull., 38(9), 795–801. 10.1016/S0025-326X(99)00043-0.
Geyer, R., Jambeck, J.R., Law, K.L, 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3(7). 10.1126/sciadv.1700782.
Gusev, A.A., Martin, I.M., Mello, M.G.S., Pankov, V., Pugacheva, G., Schuch, N.G., 2004. Bidecadal cycles in liquid precipitations in Brazil. Adv. Space Res., 34(2), 370–375. doi: 10.1016/j.asr.2003.03.048.
Hinojosa, I.A., Thiel, M., 2009. Floating marine debris in fjords, gulfs and channels of southern Chile. Mar. Pollut. Bull. 58(3), 341–350. 10.1016/j.marpolbul.2008.10.020.
Ivar do Sul, J.A., Spengler, A., Costa, M.F., 2009. Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). Mar. Pollut. Bull. 58 (8) (2009), pp. 1229–1244. 10.1016/j.marpolbul.2009.05.004.
Ivar do Sul, J.A., Costa, M.F., 2007. Marine debris review for Latin America and the Wider Caribbean Region: From the 1970s until now, and where do we go from here? Mar. Pollut. Bull. 54 (8), 1087–1104. https://doi.org/10.1016/j.marpolbul.2007.05.004.
Ivar do Sul, J.A., Costa, M.F., 2014. The present and future of microplastic pollution in the marine environment. Environ. Pollut. 185, 352–364. https://doi.org/10.1016/j.envpol.2013.10.036.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Marine pollution. Plastic waste inputs from land into the ocean. Science 347, 768–771. https://doi.org/10.1126/science.1260352.
Li, W.C., Tse, H.F., Fok, L., 2016. Plastic waste in the marine environment: a review of sources, occurrence and effects. Sci. Total Environ. 566–567 (2016), 333–349. https://doi.org/10.1016/j.scitotenv.2016.05.084.
Loulad, S., Houssa, R., Rhinane, H., Boumaaz, A., Benazzouz, A., 2017. Spatial distribution of marine debris on the seafloor of Moroccan waters. Mar. Pollut. Bull. 124(1), 303–313. 10.1016/j.marpolbul.2017.07.022.
Petersen, E.S., Krüger, L., Dezevieski, A., Petry, M.V., Montone, R.C., 2016. Incidence of plastic debris in Sooty Tern nests: A preliminary study on Trindade Island, a remote area of Brazil. Mar. Pollut. Bull. 105(1), 373–376. 10.1016/j.marpolbul.2016.02.036.
Rosevelt, C., Huertos, M.L., Garza, C., Nevins, H.M., 2013. Marine debris in central California: quantifying type and abundance of beach litter in Monterey Bay, CA. Mar. Pollut. Bull., 71(1-2), 299–306. 10.1016/j.marpolbul.2013.01.015.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2018. Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain). Mar. Pollut. Bull. 133 (2018), 636–646. https://doi.org/10.1016/j.marpolbul.2018.06.010.

Ryan, P.G., 2015. Does size and buoyancy affect the long-distance transport of floating debris? Environ. Res. Lett. 10, (2015). https://doi.org/10.1088/1748-9326/10/8/084019 084019.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92(1–2), 170–179. 10.1016/j.marpolbul.2014.12.041.

Santos, I.R., Friedrich, A.C., Wallner, M., Fillmann, G., 2005. Influence of socio-economic characteristics of beach users on litter generation. Ocean Coast. Manage. 48(9-10), 742–752. 10.1016/j.ocecoaman.2005.08.006.

Santos, I.R., Friedrich, A.C., Wallner-Kersanach, M., Fillmann, G., Shiller, R.V., Costa, R., 2004. Geração de resíduos sólidos pelos usuários da praia do Cassino, RS, Brasil. Gerenciamento Costeiro Integrado 3 (2004), 12–14.

Santos, I.R., Friedrich, A.C., Barretto, F.P., 2005b. Overseas garbage pollution on beaches of northeast Brazil. Mar. Pollut. Bull. 50 (2005), 778–786. https://doi.org/10.1016/j.marpolbul.2005.04.044.

Schwarz, A.E., Ligthart, T.M., Boukris, E., van Harmelen, T., 2019. Sources, transport, and accumulation of different types of plastic litter in aquatic environments: a review study. Mar Pollut Bull 143, 92–100.

Sheavly, S.B., Register, K.M., 2007. Marine debris and plastics: environmental concerns, sources, impacts and solutions. J. Polym. Environ. 15(4), 301–305.

Turner, A., Holmes, L, 2011. Occurrence, distribution and characteristics of beached plastic production pellets on the island of Malta (central Mediterranean), Mar. Pollut. Bull. 62(2), 377–381. 10.1016/j.marpolbul.2010.09.027.

Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., Janssen, C.R., 2015. Microplastics in sediments: a review of techniques, occurrence and effects. Mar. Environ. Res. 111 (2015), 5–17. https://doi.org/10.1016/j.marenvres.2015.06.007.

Velander, K.A., Mocogni, M., 1998. Maritime litter and sewage contamination at Cramond Beach, Edinburgh – a comparative study. Mar. Pollut. Bull., 36(5), 385–389. 10.1016/S0025-326X(97)00204-X.

Velander, K., Mocogni, M., 1999. Beach litter sampling strategies: is there a ''Best'' Method? Mar. Pollut. Bull., 38 (12), 1134–1140. 10.1016/S0025-326X(99)00143-5.

Zhou, C., Xu Liu, Zhengwen Wang, Tiantian Yang, Linna Shi, Linlin Wang, Suwen You, Min Li, Cuicui Zhang, 2016. Assessment of marine debris in beaches or seawaters around the China Seas and coastal provinces. Waste Manage. 48, 652–660. 10.1016/j.wasman.2015.11.010.