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The influence of small human settlements on marine litter in the northeast coast of Brazil

A influência de pequenos assentamentos humanos no lixo marinho na costa nordeste do Brasil

Emerson Campos Barbosa Júnior[@, 1], Fabio Luís Galvão da Silva[1, 2], Verena Henschen Meira[1, 3], Karla Morato[1, 4], Enée Gottschalk[1, 5], Gabriela de la Rosa[1, 6], Yuri Costa[1, 7]

[@] *Corresponding author: emersonjr25@hotmail.com*
[1] *Programa de Pós-Graduação em Ecologia, Instituto de Biologia, Universidade Federal da Bahia, Rua Barão de Geremoabo, s/n,Campus de Ondina, Salvador, Bahia, 40170-115, Brazil*
[2] *Email: fgalvao3@gmail.com*
[3] *Email: verenahm@gmail.com*
[4] *Email: karlamorato@hotmail.com*
[5] *Email: enee_pgm@hotmail.com*
[6] *Email: gabrielavanegas.delarosa@gmail.com*
[7] *Email: yuricost@gmail.com*

ABSTRACT: The influence of small human settlements on the distribution of marine litter is not well known. We investigated the potential contribution of such settlements in the distribution of the abundance and richness of macro litter (>1 cm) along a beach stretch in the northeast coast of Brazil coast. In order to investigate if the garbage would increase near coastal villages, we collected stranded marine litter in 45 transects, along 8.1 km of the beach stretch, including the ocean front of two small human settlements (Siribinha and Poças). We used a generalized additive model (GAM) and found greater waste richness in Siribinha and between Siribinha and Poças. No clear variation trend was evidenced in the amount of marine litter along the sampling sites. This indicate an unsystematic pattern of the distribution of litter near small villages, opposing to patterns observed in large urban centers. Therefore, litter produced far away may be a worse problem, then local litter, in remote coastal areas.

Keywords: Brazil, debris, pollution.

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RESUMO: A influência dos pequenos assentamentos humanos na distribuição do lixo marinho não é bem conhecida. Investigamos a contribuição potencial de tais assentamentos na distribuição da abundância e riqueza de macro lixo (>1 cm) ao longo de uma faixa de praia na costa nordeste no Brasil. A fim de investigar se o lixo aumentaria próximo às vilas costeiras, coletamos lixo marinho encalhado em 45 transectos, ao longo de 8,1 km de faixa de praia, incluindo a frente de dois pequenos assentamentos humanos (Siribinha e Poças). Utilizamos um modelo aditivo generalizado (GAM) e encontramos maior riqueza de resíduos em Siribinha e entre Siribinha e Poças. Nenhuma tendência de variação clara foi evidenciada na quantidade de lixo marinho ao longo dos locais de amostragem. Isto indica um padrão não sistemático da distribuição de lixo perto de pequenas vilas, em oposição aos padrões observados nos grandes centros urbanos. Portanto, lixo produzido longe pode ser um problema pior, do que lixo local, em áreas costeiras remotas.

Palavras-chave: Brasil, detritos, poluição.

1. INTRODUCTION

Marine litter is of major concern in coastal and oceanic environments (Galgani *et al.* 2015; Iñiguez *et al.* 2016). Impacts of macro litter (*i.e.* > 0.1 cm) are associated with human health and safety, aesthetic, economic impacts and mortality of marine organisms by ingestion and entanglement (Goldberg 1995; Sheavly and Register 2007; Gall and Thompson 2015). Besides these direct impacts, marine litter also contributes to the spread of pollutants (Carpenter *et al.* 1972; Islam and Tanaka 2004), opportunistic pathogens (Goldberg 1995; Zettler *et al.* 2013) and contributes to introduction of invasive species (Barnes 2002).

The main items that compose marine litter are generally products of human consumption activity. One of its sources is the continent, where materials are used and discarded, reaching the marine environment through watercourses, winds or sewage. Another source is the litter generated by human offshore activities. These sources range from recreational activity (tour boats) to industrial activities such as fishing vessels, merchant, military and oil platforms (Sheavly and Register 2007).

Marine litter can virtually be found in all oceanic and coastal regions of the globe, carrying its impacts from places like sandy beaches in large cities to remote sites such as oceanic islands and Antarctic region (Barnes 2002). Due to this potential for dispersal and impact caused by marine litter, researchers have turned their attention to describing spatial patterns and composition of litter around the globe.

Coastal environments have been the subject of many studies on marine macro litter (Ivar do Sul and Costa 2007; Galgani *et al.* 2015; Iñiguez *et al.* 2016). Some researchers have attempted to describe the distribution of macro residues in these environments (*e.g.* Smith *et al.* 2014; Portman and Brennan 2017). The main patterns found are related to the distribution and composition of garbage, such as increase in the amount of garbage near large urban centers (Leite *et al.* 2014) and large accumulations of garbage in places where humans are present (Sseptiningtiyas *et al.* 2018) - most situations the plastic is main item found (Ivar do Sul and Costa 2007; Smith *et al.* 2014; Iñiguez *et al.* 2016). Another important topic investigated by researchers is the economic cost of cleaning up and recovering the damages caused by marine litter (McIlgorm *et al.* 2011).

The litter found in coastal regions may come from sources such as: the ocean (waste brought by an interaction of ocean currents, waves and wind), the disposal by local beach users and from nearby cities (Coe and Rogers 1997; Ribic *et al.* 2012). It is well documented that sites close to big cities have a greater abundance and richness of waste material (*e.g.* Leite *et al.* 2014; Becherucci *et al.* 2017) and a large part of the studies on the distribution of macro waste are carried out in large cities (Ivar do Sul and Costa 2007). Nevertheless, litter accumulation is not only observed near large urban centers but also in to remote beaches in remote islands and in Antarctica (Barnes *et al.* 2009), carried by the action of ocean currents and winds.

Watts *et al.* (2017) carried out monthly systematic surveys over six years on nine beaches and observed that, despite monthly cleaning efforts and efforts to reduce littering by visitors, there was an increase of up to 120% in amount of litter on the studied beaches, mainly plastic fragments associate with the marine source. Therefore, small urban settlements may receive a larger litter load from far locations than what is locally produced. These results reveal the need for greater concern on the part of public authorities and the population regarding floating waste, especially plastics.

Regarding the destination of solid waste, Brazilian legislation has made great progress with the National Policy on Solid Waste (Brazil 2010 – NPSW: Law n° 12,305). This law articulates the Public power, productive sector and civil society in policies that seek to balance environmental preservation and sustainable economic

development. NPSW establishes selective collection, recycling, waste treatment and environmentally appropriate final disposal of waste. In addition, it assigns responsibility for hazardous waste companies (*e.g.* pesticides, batteries and electronic components) to structure and implement, regardless of the public cleaning system, reverse logistics systems. However, results from this type of policy may not be effective and floating waste produced in large urban centers may reach more distant locations.

Although we know the magnitude of the influence of large urban centers and that litter from ocean sources also contributes to the accumulation of litter on beaches, the contribution of small urban settlements (*i.e.* villages) on the distribution of garbage on adjacent beaches is still unknown. This can be associated to the difficulty of access and associated logistical constraints (Ivar do Sul and Costa 2007). Although there are already some studies on isolated beaches (Taffs and Cullen 2005, Smith *et al.* 2014), sparsely populated areas (Eriksson *et al.* 2013) and small human settlements (Taffs and Cullen 2005, Bennett-Martin *et al.* 2015; Becherucci *et al.* 2017; Portman and Brennan 2017; Sseptiningtiyas *et al.* 2018), these were not intended to investigate the contribution of these sites to the distribution of waste.

The present study aims to investigate the contribution of small human settlements on the distribution of the abundance and richness of macro waste (>1 cm) along a beach stretch in Bahia, northeast Brazil. Our hypothesis was that the beach stretch near the small villages of Siribinha and Poças would present a greater amount and variety of garbage.

2. MATERIALS AND METHODS

The study area is located in a continuous sandy beach, about 8 km long, located in the municipality of Conde, northeastern Brazil (Fig. 1, Supplementary data Fig.3). The villages of Siribinha and Poças are located in this beach stretch, both villages have about 500 inhabitants and the distance between them is about 4 km. The municipality of Conde has 26 thousand inhabitants (IBGE 2018), distancing itself 170 km from Salvador (BA, Brazil) and 120 km from Aracaju (SE, Brazil), which are the closest large cities. Siribinha and Poças are approximately 10 km away from the center of Conde. Several well-preserved habitats can be found at this region, such as mangroves, sand dunes, exposed and protected beaches and costal reefs. Fishing is the main subsistence activity for the residents of the region.

We investigated the distribution of macro residues along the beach stretch starting at the beginning of the Barra region, following the village of Siribinha and ending at the end of Poças village (Fig. 1). We established the first point 180 m from the beginning of the Barra region and 44 other sampling points equidistant 180 m between them, totaling about 8 km from point 1 (Fig. 1). At each sampling point, a transect was established orthogonal to the coast. The transects were four meters wide in width and length ranged from the water line at low tide to the beginning of dune vegetation (varied between 6 and 36 meters), where we collected all the macro residue found (> 1 cm). The collected materials were sorted by type, making up different categories (*i.e.* plastics, wood, metal, building materials, glass and multi materials). Sub-categories were created in each of them to identify

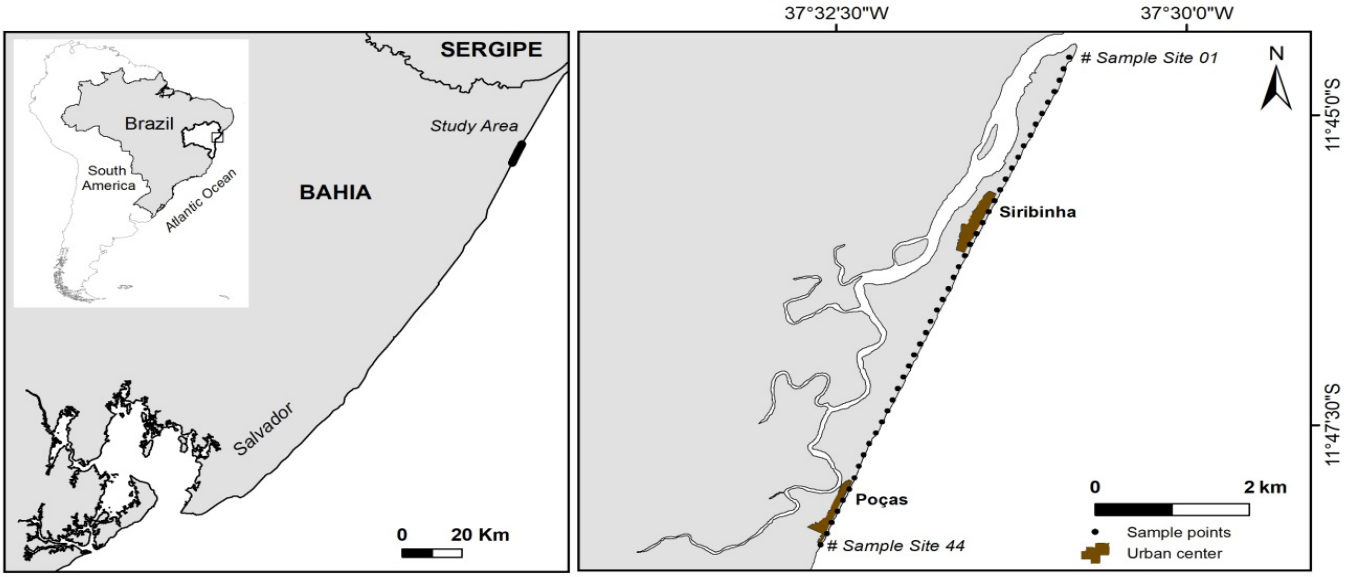

Figure 1. Localization and distribution of the sampling points in the beach stretch located at the municipality of Conde (BA).

Figura 1. Localização e distribuição dos locais de amostragem ao longo da faixa de praia localizada na municipalidade do Conde (BA).

the different objects within each category (adapted from Leite *et al.* 2014). In this way, the richness of the materials (Supplementary data Table 1) was estimated. We used these values to estimate the total abundance of materials, including their types and the richness of materials (*i.e.* variety of materials).

The data of materials total abundance of each category (*e.g.* plastic, wood, and metal) and of the richness along the sample points were analyzed using generalized additive models (GAM) (R Development Core Team, 2016). We chose this approach because it allows us to capture non-linear relationships, allowing the test of our hypothesis that there will be greater quantity and variety of garbage near the villages (two Gaussian curves). To investigate the potential differences due to the different sampled areas (*i.e.* beach length), we tested if there would a statistically significant relationship between the extent of the collection site (*i.e.* beach length) and the total amount and richness of litter sampled (Supplementary data Figs 1 and 2).

In addition, we performed the Shapiro-Wilk normality test to evaluate the normality of the distribution of our data and the Breusch-Pagan homogeneity of variance test to verify if our data had a homogeneous variance. These tests were done for the charts of richness and total abundance, as these were the only ones that were part of our hypothesis. We established the "alpha" of 0.05.

3. RESULTS

We collected a total of 1,501 items, separated into six residue categories (Table 1). The main material found was plastic (89.2%), followed by residues of wood (6%), building material (2.4%), metal (1.7%), glass (0.3%) and varied materials (0.3%). Among materials of all kinds, the most recurrent items were plastic fragments (soft at 39 points, hard at 21 points, flexible at 30 points, plastic bottle cap (21 points), and styrofoam (27 points) (more details in Supplementary Material 1). Examples of garbage from the subcategories are: (a) plastic - PET bottle, fragments and nylon; (b) wood - coconuts, paper and coal; (c) building material – cement, bricks and tile fragments; (d) metal – tin, aluminum paper and wire; (e) glass – bottle and fragment; and (f) multi materials – absorbent and cigarette lighter (Supplementary data Datasheet 1).

The data of litter richness and litter total abundance passed the normality test ($p = 0.08$) and the homogeneity test ($p = 0.50$). There was no statistically significant relationship between the extent of the collection site and: (a) the total amount of waste sampled ($p = 0.26$, $R^2 = 0.006$); and (b) nor with the richness of sampled material ($p = 0.45$, $R^2 = 0.009$), so there was no bias in our collected data (Supplementary data Figs. 1 and 2).

Table 1. Total amount (abundance) of Litter of each type of collected material.

Tabela 1. Quantidade total (abundância) de lixo por tipo de material

Litter Categories	Number of items	Relative abundance (%)
Plastic	1340	89.3
Wood	90	6.0
Building material	36	2.4
Metal	25	1.7
Glass	5	0.3
Other (varied materials)	5	0.3
Total	**1501**	**100**

We found no obvious tendency of increase or decrease in the amount of macro litter along the sample points ($p = 0.28$, $R^2 = 0.05$) (Fig. 2a). We found a significantly greater richness of macro residues ($p = 0.03$, $R^2 = 0.17$) along the village of Siribinha and along the region between Siribinha and Poças, demonstrated by the decrease curve in Barra and Poças and increase in the central points (Fig. 2b). Among the most abundant materials there were plastic fragments (soft - 471 items, hard - 126 items, flexible - 99 items), plastic bottle cap (77 items), styrofoam (132 items), and nylon (85 items) (Supplementary data Datasheet 1).

We found greater quantity of metal in the village of Siribinha and in the region between Siribinha and Poças, although in this case most of the observed values were low (Fig. 2d). We found greater quantity of wood in the village of Siribinha and its vicinity – we also found a greater abundance of wood near the village of Poças, next to the village, towards Siribinha (Fig. 2c). Plastic showed a similar distribution to that of the total abundance of macro residues due to its large abundance in almost all sample points (Fig. 2e). We found: (a) nearby the village of Poças: large quantities of plastic; and (b) nearby the village of Siribinha: plenty of plastic (Fig. 2e), wood (Fig. 2c - mainly 2 items - 24 fragments of paper and 9 fragments of wood) and construction material (point 16 - 31 items - 86% of materials collected from this category).

Building materials, glass and other (varied materials) were restricted to few points (less than 5 sample points). Aditionally, at points (*i.e.* 13, 29, 30, 35 and 37) litter was trapped in patches of wrecked river vegetation (Supplementary data Fig. 4) and garbage associated with it, causing disparity in abundance values (Fig. 2). On the other hand, in the Barra region and in the village of Poças, we found a small amount of macro residue in almost all the sites collected (Fig. 2).

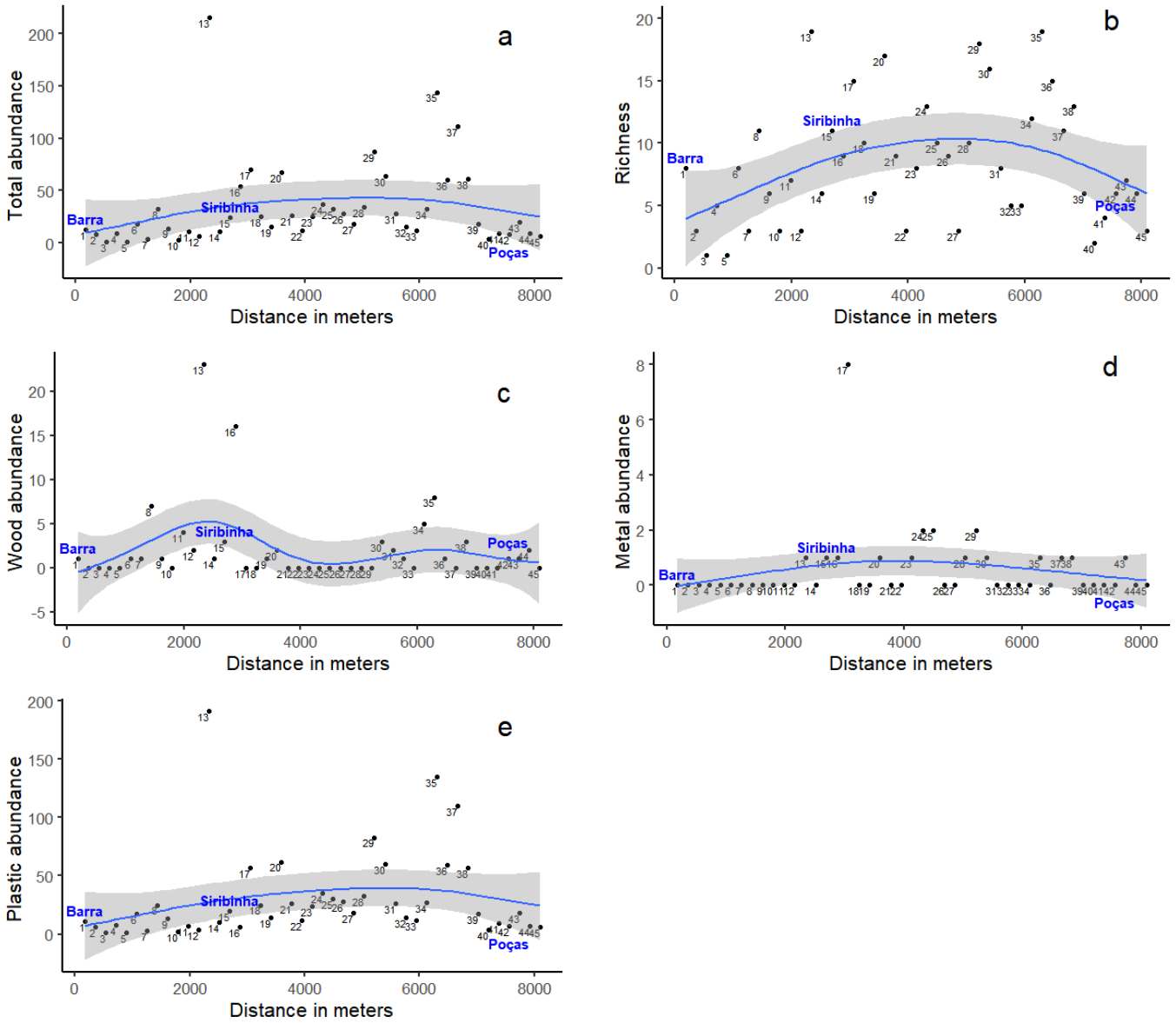

Figure 2. Distribution of macro residues (> 1 cm) along the beach stretch in a part of the coast of the municipality of Conde (BA) - the total extension of the village of Siribinha are transects 13, 14, 15, 16 and 17 (point 15 corresponds to the center of the village) and the Poças extension are points 40, 41, 42, 43 and 44 (point 42 corresponds to the center of the village). a) Distribution of total abundance of macro residues ($p = 0.28$ $R^2 = 0.05$). b) Distribution of richness of macro residues ($p = 0.033$ $R^2 = 0.17$). c) Distribution of abundance of wood. d) Distribution of the abundance of metal. e) Distribution of abundance of plastic.

Figure 2. Distribuição de macro-resíduos (>1 cm) ao longo da praia na linha de costa da Munincipalidade de Conde (BA) - a extensão total da vila Siribinha corresponde aos pontos 13, 14, 15, 16 e 17 (o ponto 15 corresponde ao centro da vila). A extensão de Poças corresponde aos pontos 40, 41, 42, 43 e 44 (o ponto 42 corresponde ao centro da vila). a) distribuição total da abundância de macro resíduos ($p=0.28$ $R^2=0.05$). b) distribuição de riqueza de macro resíduos ($p=0.033$ $R^2=0.17$). c) distribuição da abundância de madeira. d) distribuição da abundância de metal. e) distribuição da abundância de plástico.

4. DISCUSSION

Our main results contradict our expectations that there would be greater abundance and richness of litter in the coastal region near the villages. Two possible causes for this result are that: (1) exotic litter (oceanic or farway produced) accumulation is larger than local one; and (2) local community practices, since the municipality and the small shopkeepers (who have beach stalls), clean up beach stretches near the places where chairs and umbrellas are placed for visitors. The contribution of this clean up likely is unequal, depending on the site, amount and does not seem to have efficiency for some types of materials, such as wood (due to its size and shape – in Siribinha region), fragments of plastics and litter of smaller size.

In the region of Siribinha and between Siribinha and Poças there is a greater abundance and variety of litter, possible due to non-local sources and also small types of plastic fragments (<10cm,> 1cm) that are not usually collected. Contrary to results found in big cities (e. g. Leite *et al.* 2014; Becherucci *et al.* 2017), with an increase in the distance from the village (in the region between villages), there was an increase in the amount of garbage. In the region of Barra, part of the composition of the macro residues were of foreign origin (pers. obs.), suggesting that these have come across the ocean. Possibly there is a great contribution of oceanic litter acting as a whole along this region. Thus, there may be oceanic litter produced in large Brazilian urban centers reaching the most remote locations. This possibility seems to indicate that despite the advance of the National Solid Waste Policy (NSWP), there is still need for a better articulation between the actors involved (*i.e.* State, society and the productive sector) in relation to the production and proper disposal of litter, especially plastic (most abundant material), prioritizing measures for this kind of material in municipal solid waste plans.

We observed that high amounts of litter associated (*i.e.* trapped) wrecked river vegetation (Supplementary data Fig. 4). The points with such vegetation showed the higher abundance and richness and this may have an effect in the detected patterns. Therefore, we reanalyzed our data by excluding this points (data were normal, homogeneous, and without bias) (Supplementary data Fig. 5) but observed similar trends. Nevertheless the total abundance of garbage ($p = 0.02$ $R = 0.20$) and abundance of plastic ($p = 0.01$ $R = 0.23$) were also significant. These analyses also showed a significant increase in the amount of garbage region of Siribinha and between Siribinha and Poças (general pattern for total abundance, richness and abundance of plastic). Therefore, reassuring our previously described patterns.

The abundance of plastic waste in our study coincides with the results of other studies (Derraik 2002; Santos *et al.* 2009; Debrot *et al.* 2013; Leite *et al.* 2014), which shows that this material is the main solid pollutant found on the beaches. Derraik (2002) suggested that the large amount of plastic found among the marine litter may be related to the fact that plastic is a lightweight, resistant, durable, cheap, which presents buoyancy and with a long reach of dispersion, being this one of the major causes of environmental problems in present days. Thus, this item represents a global problem and may even reach remote places such as uninhabited oceanic islands (Lavers *et al.* 2019).

There seems to be no marked contribution of residues near the two studied small villages, our results differed from our expectations and that of the villages investigated by Taffs and Cullen (2005) and Bennett-Martin *et al.* (2015). The latter authors examined coastal villages with different population size with the beach separated by distance categories and showed that most of the small communities had fewer debris. Studies in isolated beaches or sparsely populated areas observed higher (*e.g.* Smith *et al.* 2014, 4,520 items; Eriksson *et al.* 2013, 6,389 items) or similar number of litter items (Becherucci *et al.* 2017; 2,226) to our study. We observed that several studies did not formally tested for differences (likely due to the absence of hypothesis), used very different methodologies and did not show raw data, hampering possible comparisons with our study.

CONCLUSIONS

The village of Siribinha presented relatively more macro residues than Poças, and, contrary to our expectations, the area with the greatest abundance and richness of waste was the region between these settlements. This indicates that there is a great contribution of oceanic litter along the coastline and an unsystematic pattern of the distribution of garbage near small villages. Opposing to patterns observed in large urban centers, there was an increase in the amount of marine litter with distance from the village (in the region between villages). The two villages, with approximately the same population number, have different amounts of litter. Litter from oceanic sources presents a higher risk of pollution to beaches near the small villages. It is suggested that the next studies classify the waste according to its origin, because some of this oceanic litter may be produced in large Brazilian urban centers. This may confirm the suspicion that despite the advance of the National Solid Waste Policy (NSWP), the integration between the State, society and productive sector to reduce the problem of waste is still incipient.

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