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Small microplastics on beaches of Fernando de Noronha Island, Tropical Atlantic Ocean

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Abstract

Oceanic islands are important areas of environmental, social, economic, and scientific interest. Therefore, it is essential to identify pollutants in these environments, including large (1 mm to ≤ 5 mm) and small microplastics (SMP) (1 µm to ≤ 1 mm). Here, SMP were identified and characterized in the windward (WW) and leeward (LW) beaches of Fernando de Noronha Island. Samples were collected from 900 cm^2 quadrants on the strandline of 15 sandy beaches and were sieved through stainless steel sieves with 1 mm mesh. The SMP were characterized according to their shape, colour, and size. Synthetic fibres and fragments were identified, and synthetic fibres were predominant. Statistical differences were not found between the WW and LW beaches (160.0±137.5 particles m^{-2} and 128.0±84.3 particles m^{-2}, respectively; Mann-Whitney *U* test: U=198.5; p=0.81) in relation to the total amount of SMP deposited on the beaches. Also, both types/shapes were present in the two groups of beaches (Friedman's test, X^2 r=6.09; p=0.91). The environmental forcings controlling the transport and potential deposition of synthetic fibres may have been different from those acting on fragments that more resembled the grains of sand in the beaches. Although it is difficult to prevent allochthonous sources of SMP at the small scale, management actions on the island are mandatory to prevent autochthonous sources.

Descriptors: Plastic pollution, Oceanic islands, Marine conservation, Atlantic Ocean, Brazil.

INTRODUCTION

Scientists, civil society, and governments have recently (< 10 y) increasing concerns about the impacts of microplastic pollution on marine ecosystems (Hu et al., 2019; Van Wijnen et al., 2019). Microplastics are plastic particles with a size of 1 µm to 5 mm; because they have diverse behaviours within marine habitats (i.e. transport mechanisms and potential impacts), they can be classified as large (1 mm to ≤ 5 mm) or small (1 µm to ≤ 1 mm) microplastics (SMP) (Van Cauwenberghe et al., 2015; Gigault et al., 2018). However, SMP and large microplastics have the same sources (Boucher and Friot, 2017). Primary SMP are already at the microscopic scale when they reach the sea, such as microbeads used in cosmetics; they can enter marine environments from sewage discharge on land (Browne et al., 2011; Boucher and Friot, 2017). On the other hand, secondary SMP originate from the degradation and fragmentation of relatively larger plastics in the environment (Frias and Nash, 2019).

Generally, the smaller the size of the microplastics, the greater the number of marine animals susceptible to interaction (e.g. ingestion) with these particles; they then have the potential to be introduced into marine trophic webs (Gusmão et al., 2016; Wang et al., 2019). Also, the harmful effects of SMP are potentially worse when organic or inorganic pollutants are adsorbed onto

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SMP, as they can be released into the digestive tract of organisms, thereby even compromising human food security (Barboza et al., 2018).

Within the range of marine habitats that are already shown to be contaminated by microplastics are remote oceanic islands, where allochthonous sources (e.g. marine currents and ships) can be significant sources of plastics with a relatively larger size range (Edo et al., 2019; Lavers et al., 2019; Ryan et al., 2019). Plastic particles are commonly found in higher amounts on windward (WW) beaches of these islands owing to the direct action of physical forcing (e.g. Ivar do Sul et al., 2009; Monteiro et al., 2018). On the other hand, autochthonous sources are significant on touristic islands where there is permanent human occupation (Debrot et al., 2013; Schmuck et al., 2017). Independent of the predominant source of plastic, oceanic islands can be sources but also temporary reservoirs or final sinks of plastics in the oceans.

In the Atlantic Ocean, the UNESCO Natural Heritage of Humanity island of Fernando de Noronha covers approximately 20 km^2; approximately 3,000 inhabitants live on the island (IBGE, 2010), but the number of tourists reaches > 50,000 in the high season (austral summer season). The island is part of the Environmental Protection Area of Fernando de Noronha - Rocas - Saint Pedro and Saint Peter Archipelago and the National Marine Park of Fernando de Noronha (PARNAMAR). It has a crucial role in the preservation of threatened species such as marine turtles (*Caretta caretta*, *Chelonia mydas,* and *Eretmochelys imbricata*), fish (Lemon Shark - *Negaprion brevirostris*), seabirds (Shearwater - *Puffinus lherminieri*), and echinoderms (Starfish - *Echinaster (Othilia) guyanensis*). In addition, the Golfinhos Bay hosts a permanent population of rotator dolphins (*Stenella longirostris*) (Bellini and Sanches, 1996; Serafini et al., 2010). All endemic and migratory species are at imminent risk of plastic pollution on the island.

This study is part of a broader project on microplastic pollution in Brazilian oceanic islands. Sediment samples were fractionated with a 1 mm sieve, and large microplastics and SMP were preferentially retained in two different fractions. Large microplastic data were previously published (Ivar do Sul et al.,

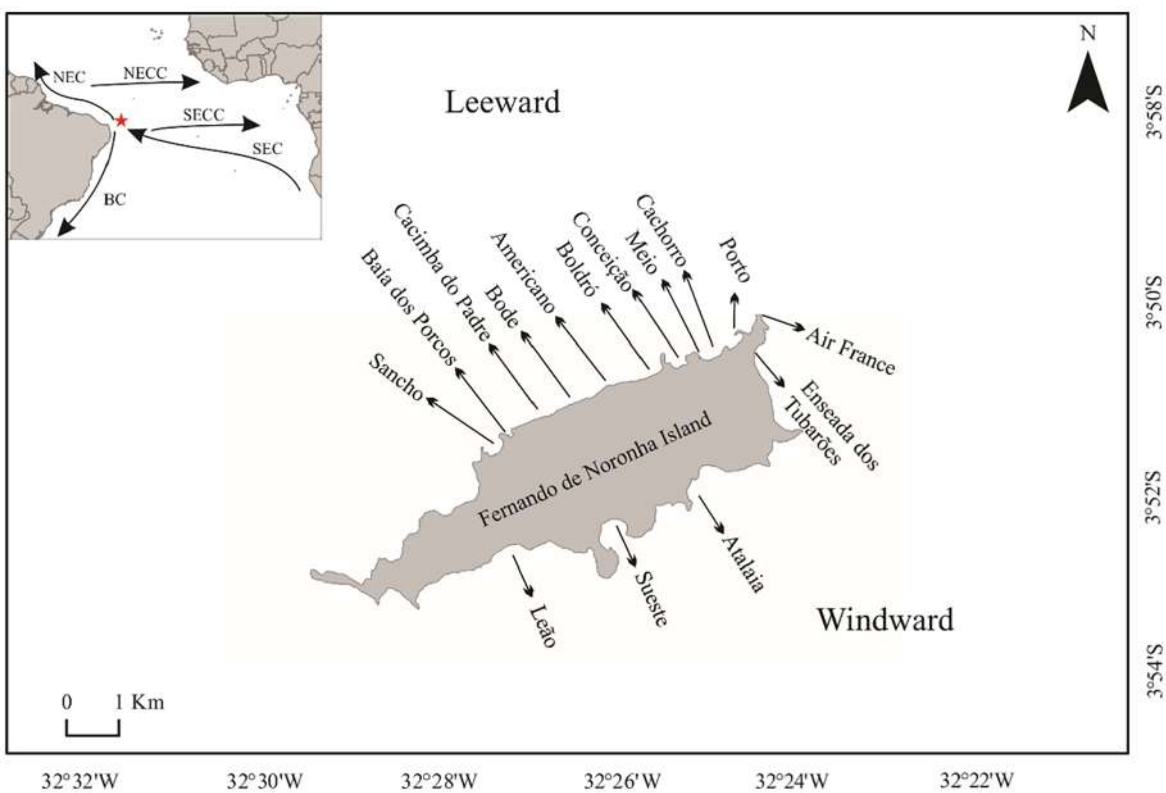

Figure 1. (A) Location of the Fernando de Noronha Island in the west of the Equatorial Atlantic Ocean and the main surface currents (SEC = Equatorial South Current; NBC = Northern Brazil Current; BC = Brazilian Current, SECC = South Equatorial Counter Current; NECC = North Equatorial Counter Current). (B) Location of beaches analyzed on the main island of Fernando de Noronha, divided into leeward and windward.

2017). Thus, the present study aimed to identify and characterize SMP in sandy beaches of Fernando de Noronha Island. Here we focused on SMP with a small spatial distribution and tested two hypotheses, as follows: (1) WW beaches are more contaminated by SMP than LW beaches and (2) are recurrent among the WW and LW beaches on the island.

MATERIAL AND METHODS

Study area

Fernando de Noronha is a volcanic archipelago located in the Tropical Atlantic Ocean (Figure 1). Its geological nature is formed by submarine volcanic mountains emerging from the fracture zone of Fernando de Noronha (Calliari et al., 2016), and it forms 21 small islands and cliffs. The weather is tropical with an average annual air temperature of 28±4°C (Mohr et al., 2009). It has two defined seasons, namely the rainy season from February to July and the dry season from August to January (Mohr et al., 2009). The island is influenced by the southeast trade winds, which are more intense in June–August and create higher swells on the WW side of the archipelago (Calliari et al., 2016). The samples used in this study were collected in the austral summer season (March) before the higher swells reached the island. The islands are also under the influence of the South Equatorial Current (SEC) (Cirano et al., 2006), which flows from east to west and has a low concentration of suspended matter (Eston et al., 1986; Stramma and England, 1999). The local hydrodynamics and island topography generate vertical turbulence that allows the rise of deeper waters rich in nutrients (upwelling), thereby increasing the plankton biomass, which is a phenomenon called the island mass effect (Lira et al., 2014; Tchamabi et al., 2017).

The main island of the Fernando de Noronha Archipelago, which is also called Fernando de Noronha, has 37 km of coastline, of which 28.5 km (77%) are rocky shores and 8.4 km (23%) forms 32 beaches with 15 sandy beaches (Calliari et al., 2016). These sandy beaches are composed of carbonate sand, which is derived from coral reefs and volcanic rocks, with grain sizes varying from 0.1 mm to 0.5 mm (Barcellos et al., 2011; Manso et al., 2011). For this study, beaches were grouped by WW beaches, which are directly influenced by wind, marine currents, and waves; and LW beaches, which are relatively protected from the action of wind and currents.

Sampling and sample treatment

Sediment samples were collected on the strandline of five WW and ten LW beaches by scraping the sand from 30 × 30 cm (900 cm^2) quadrants (Ivar do Sul et al., 2009). Three quadrants were sampled on each beach with one at the centre and two at each end of the beach arc. However, only one quadrant (in the centre) was sampled on Porcos and Cachorro beaches and two quadrants (at the ends of the beach arc) were sampled on Porto beach owing to the beach lengths (total of 40 samples). All samples were kept in sealed plastic bags until analysis. Particles resembling these bags were not identified in the samples; thus, they were not considered a potential contamination source of microplastics here.

In the laboratory, sediment samples were oven-dried and sieved through a stainless steel mesh of 1 mm. The fraction smaller than 1 mm (SMP + sediment) was then submitted to density separation following well-established methods (e.g. Martins and Sobral, 2011) previously detailed by Pinheiro et al. (2019). Negative blanks were performed to control possible contamination from the commercial table salt and distilled water used for density separation. Particles (including fibres) resembling those presented in this study were not identified in the blank samples and were not considered potential sources of SMP here. Filters were oven-dried in Petri dishes at 40°C and analysed under Carl Zeiss Stemi 2000-C stereomicroscope (1×). During the laboratory procedures, samples were kept closed with a glass lid or Al foil to avoid external contamination (i.e. airborne fibres). SMP particles were identified according to their type/shape (e.g. fragments or synthetic fibres), colour, and size (length and total area). Fibres were recognized using visual criteria available in the literature, including the uniform diameter of fibres or the presence of bends, or by their brightness and diverse colours (i.e. blue and red), which did not resemble marine animal or plant tissue (Browne et al., 2011). Images were obtained using AxioVs40 V 4.8.2.0 software from Carl Zeiss Vision.

Data analyses

The total density (amounts) of SMP was expressed as the number of particles per square metre. The size of the SMP was expressed in millimetres and the area was expressed in square metres. The Gaussian distribution of the data was tested, and the data showed a nonparametric distribution. The nonparametric Mann-Whitney *U* test (α=0.05) was then used to check the significant differences in the amount of SMP between WW and LW beaches (Hypothesis 1). To compare the SMP types within beach groups (WW or LW), a two-way analysis with Friedman's test (α=0.05) was used for multiple comparisons (Hypothesis 2). Data were also compared with those of a previous work (Ivar do Sul et al., 2017) to check the co-occurrence of SMP and relatively larger microplastics in beaches on the island.

RESULTS

SMP were reported in all sediment samples from Fernando de Noronha Island (Figure 2). A total of 504 SMP particles were identified. Synthetic fibres corresponded to 90% (n=459) (Figure 3) and fragments accounted for approximately 10% (n=45) of the particles. Synthetic fibres were predominant in all beaches and quadrats, except for one quadrat from Meio Beach (Table 1). Other types of SMP (e.g. microbeads) were not detected at this time.

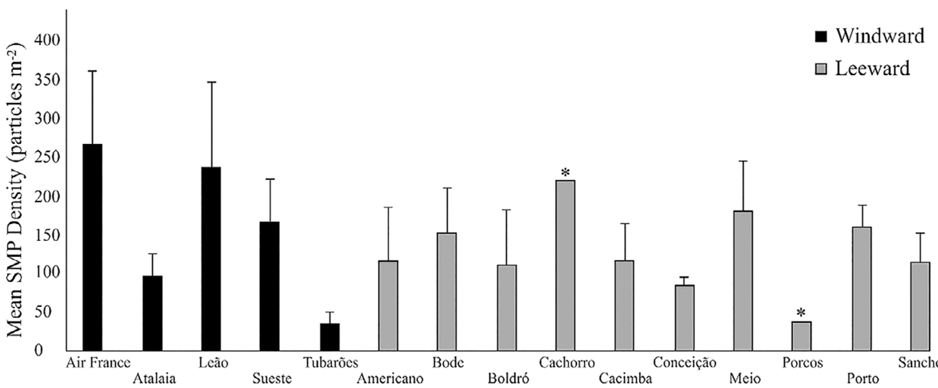

Figure 2. Mean SMP density (particles m^{-2}) on the windward and leeward beaches of Fernando de Noronha Island, Tropical Atlantic Ocean. *Total values of Porcos and Cachorro beaches. Error bars represent the standard error.

Figure 3. Photographic examples of synthetic fibres found on beaches of Fernando de Noronha Island.

Table 1. Density, size e area of fragments and synthetic fibres found on windward and leeward beaches of Fernando de Noronha Island, Tropical Atlantic Ocean. E – East; M – Middle; W – West. *Underestimated.

	Beach	Position	Density (particles m^{-2})			Total area (m^2)		Total size (mm)
			Fragment	Fiber	Total	Fragment	Fiber	Fragment
WINDWARD	*Leão*	E	-	155.6	155.6	-	$2.4x10^{-5}$	-
		M	-	100	100	-	$1.4x10^{-5}$	-
		W	-	455.6	455.6	-	$6.4x10^{-5}$	-
	Sueste	E	-	55.6	55.6	-	$5.9x10^{-6}$	-
		M	11.1	211.1*	222.2	$9.7x10^{-6}$	$7.4x10^{-5}$	4.9
		W	11.1	211.1	222.2	$8.9.10^{-6}$	$3.5x10^{-5}$	9.4
	Atalaia	E	-	44.4	44.4	-	$8.5x10^{-7}$	-
		M	44.4	55.6	100	$3.7x10^{-5}$	$1.1x10^{-5}$	24.6
		W	55.6	88.9	144.4	$2.4x10^{-7}$	$2.0x10^{-6}$	1.6
	Enseada dos Tubarões	E	22.2	44.4	66.7	$1.6x10^{-5}$	$6.8x10^{-6}$	8.8
		M	11.1	-	11.1	$1.4x10^{-5}$	-	5.0
		W	22.2	-	22.2	$1.8x10^{-5}$	-	8.0
	Air France	E	-	455.6	455.6	-	$3.7x10^{-6}$	-
		M	-	188.9	188.9	-	$4.5x10^{-6}$	-
		W	-	155.6	155.6	-	$1.5x10^{-6}$	-
LEEWARD	*Porto*	E	55.6	133.3	188.9	$5.7x10^{-7}$	$3.6x10^{-6}$	2.5
		W	33.3	100	133.3	$1.7x10^{-7}$	$2.9x10^{-6}$	1.0
	Cachorro	M	-	222.2	222.2	-	$2.2x10^{-6}$	-
	Meio	E	-	188.9*	188.9	-	$4.8x10^{-6}$	-
		M	-	66.7	66.7	-	$2.5x10^{-6}$	-
		W	188.9	100	288.9	$1.9x10^{-7}$	$1.3x10^{-6}$	2.4
	Conceição	E	-	66.7	66.7	-	$2.8x10^{-6}$	-
		M	-	88.9	88.9	-	$4.8x10^{-6}$	-
		W	-	100	100	-	$2.2x10^{-6}$	-
	Boldró	E	11.1	244.4	255.6	$8.3x10^{-8}$	$6.7x10^{-6}$	0.1
		M	-	44.4	44.4	-	$1.2x10^{-6}$	-
		W	-	33.3	33.3	-	$4.2x10^{-7}$	-
	Americano	E	-	255.6	255.6	-	$7.5x10^{-6}$	-
		M	-	55.6	55.6	-	$2.0x10^{-6}$	-
		W	11.1	22.2	33.3	$3.3x10^{-8}$	$2.4x10^{-7}$	2
	Bode	E	-	122.2	122.2	-	$2.3x10^{-6}$	-
		M	11.1	255.6	266.7	$5.7x10^{-8}$	$1.0x10^{-7}$	0.1
		W	-	66.7	66.7	-	$1.7x10^{-6}$	-
	Cacimba do Padre	E	-	44.4	44.4	-	$1.6x10^{-7}$	-
		M	-	88.9	88.9	-	$2.9x10^{-6}$	-
		W	-	211.1	211.1	-	$1.9x10^{-6}$	-
	Baía dos Porcos	M	-	33.3	33.3	-	$4.1x10^{-7}$	-
	Sancho	E	11.1	66.7	77.8	$1.8x10^{-8}$	$9.2x10^{-7}$	0.2
		M	-	77.8	77.8	-	$3.8x10^{-6}$	-
		W	-	188.9	188.9	-	$1.2x10^{-5}$	-

The mean size of the particles (MSP) was 1.8±4.5 mm (MSP_{WW}=4.2±6.7 mm; MSP_{LW}=0.3±0.8 mm) (Table 1). The mean size was larger than 1 mm because longer fibres were not consistently retained by the 1 mm sieve when the sample was sieved. If all the particles were sorted on a Petri dish, then fragments would occupy an area of 1.06 × 10^{-4} m^2 (Total $area_{WW}$=1.05 × 10^{-4} m^2; Total $Area_{LW}$=1.10 × 10^{-6} m^2) while synthetic fibres would occupy a relatively larger area of 3.20 × 10^{-4} m^2 (Total $area_{WW}$=2.50 × 10^{-4} m^2; Total $area_{LW}$=7.30 × 10^{-5} m^2) (Table 1).

Regarding colours, blue, black, and colourless synthetic fibres represented nearly 100% of the plastic particles, except for a few pink/reddish coloured fibres. Among the fragments, blue fragments were predominant among SMP (80.0%; 36 particles), followed by green fragments (11.1%; 5 particles). Other colours such as white, yellow, gray, and red each represented 2.2% (Figure 4).

The amount of SMP in the WW and LW beaches ranged from 33.3±16.9 particles m^{-2} to 266.6±94.9 particles m^{-2} and from 85.1±9.7 particles m^{-2} to 181.4±64.2 particles m^{-2}, respectively. There was no statistical difference between these groups of beaches (WW beaches=160.0±137.5 particles m^{-2}; LW beaches=128.0±84.3 particles m^{-2}; Mann-Whitney *U* test: U=198.5; p=0.81) when considering the total amount of SMP, so Hypothesis 1 was not corroborated. However, the amounts of SMP were more variable among WW beaches than among LW beaches (Figure 2). In general, Air France and Leão beaches presented the highest amounts of SMP as they were both located on the WW side of the island. Considering the types of SMP, synthetic fibres and fragments were present in both WW and LW beaches (Friedman's test, X^2 r=6.09; p=0.913), thereby corroborating Hypothesis 2.

While large microplastics were previously reported on 8 of 13 beaches (Ivar do Sul et al., 2017), SMP were present on 9 of 15 beaches (Figure 5). However, both microplastic size categories co-occurred on five beaches, with three on the WW side of the island (i.e. Enseada dos Tubarões, Atalaia, and Sueste) and two on the leeward side (i.e. Bode and Porto).

DISCUSSION

Fernando de Noronha was a key island to test the hypotheses presented in this study because it is relatively isolated from the continent and directly influenced by the SEC (Figure 1), but is also inhabited and receives thousands of tourists each year (Cristiano et al., 2020). Thus, plastics were expected to originate from both allochthonous and autochthonous sources, including microplastics (Ivar do Sul et al., 2009). Although the occurrence of microplastics in relatively larger size ranges was already reported in beaches and

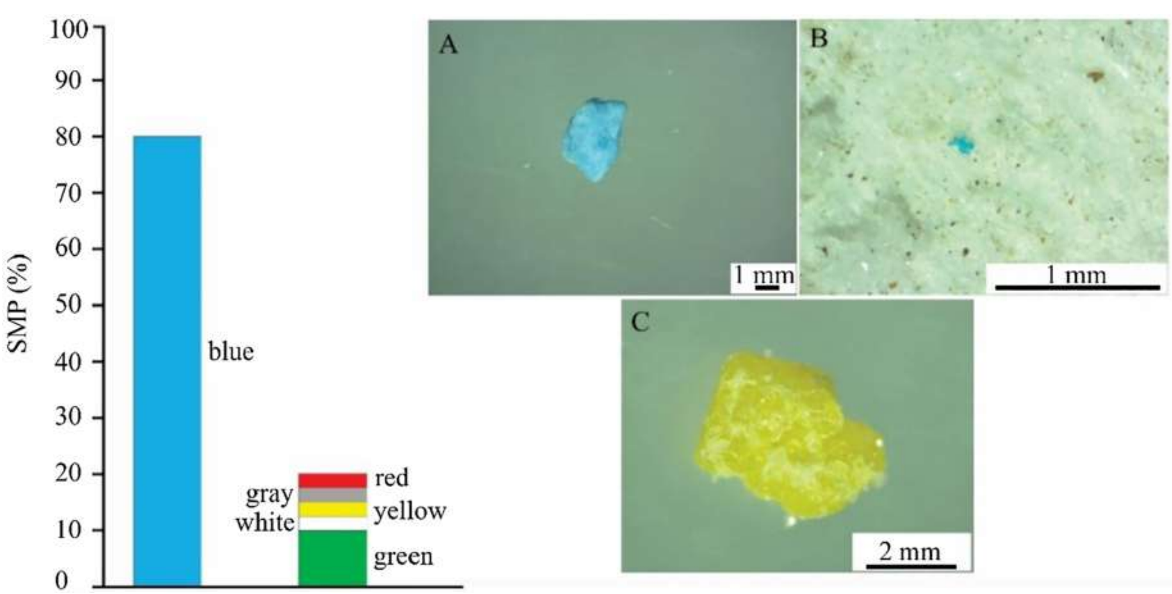

Figure 4. Colours of the plastic fragments identified on the windward and leeward beaches in Fernando de Noronha Island, Tropical Atlantic Ocean, N=45 plastic particles. A) Blue plastic fragment collected at Tubarão beach; B) Plastic fragment collected at Meio beach; C) Fragment plastics collected on the beach.

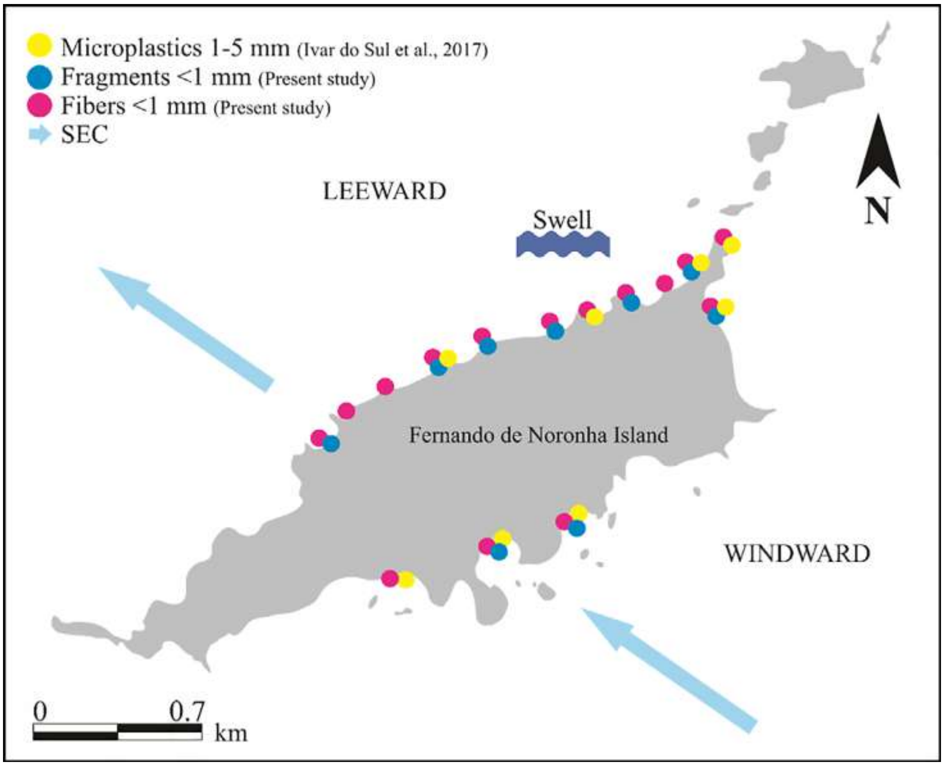

Figure 5. Larger microplastics fraction between 1-5 mm (Ivar do Sul et al., 2017)[1], a fraction less than 1 mm (this study)[2] found on the beaches in the windward and leeward of the Island of Fernando de Noronha, Tropical Atlantic Ocean. SEC: South Equatorial Current; [1]Total of 13 beaches sampled, Porcos and Cachorro beaches have not sampled in this work; [2]Total of 15 beaches sampled, including Porcos and Cachorro beaches.

in the surface waters around the island (Ivar do Sul et al., 2013; 2017), this study reported microplastics < 1 mm for the first time.

Sources of microplastics in the small size range are more difficult to identify compared with those of larger plastics. Based on the sampling strategy used in this study, no statistical difference was reported between the WW and LW beaches in relation to the amount of SMP. This indicated that independent of physical forcing and potential transport of allochthonous plastic particles, microplastics in this size range accumulated in the island beaches. On the other hand, the predominance of relatively larger microplastics (mostly fragments) in the WW beaches (Ivar do Sul et al., 2009; 2017) indicated a clearer influence of surface ocean currents on their transport and deposition on beaches. This was expected because the microplastic fragments were similar in size and shape to the grains on sandy beaches; therefore, their dynamics within the beach environment were expected to resemble sediment movement/deposition. Thus, the results presented here were influenced by the predominance of synthetic fibres (which were absent in the previous study), which had multiple and distinguished sources compared with the fragments. In addition, the deposition/removal of fibres was likely controlled by different environmental forcings; for example, local sources (i.e. wastewater discharge) and winds may have had more influence on their potential accumulation.

The results showed that WW beaches presented higher variability among beaches in relation to the amount of SMP (Figure 2). This may have been due to different small-scale current patterns, the dominant grain size in the beaches, wave action, and/or relative wind exposure. The influence of the island mass effect (Tchamabi et al., 2017) on microplastics distribution must still be investigated. It may have played a special role mainly in the transport of fibres within the insular platform and finally on their deposition on the island beaches.

The predominance of fibres was reported in previous studies, including studies on sea ice in the Arctic Ocean and in the air around an urban city (Dris et al., 2016; Bergmann et al., 2019). In the marine environment, sources are commonly associated with wastewater, but it has been shown that fishing equipment and other items can also release fibres into the sea (Mishra et al., 2019). For example, in the Saint Pedro and Saint Paulo Archipelago, which is approximately 500 km from Fernando de Noronha, industrial fishing is considered a potential source of pelagic synthetic fibres (Ivar do Sul et al., 2013). Therefore, local fishing was a possible a source of fibres in this study. Large fishing equipment (including nets and fishing lines) was previously reported to be submerged in the PARNAMAR area of the island (Link et al., 2019), and some of these items have been recognized as sources of fibres in the sea.

The potential impacts of SMP, including fibres, include their potential ingestion by organisms from the benthos community. For example, small arthropods of the order Collembola (Hexapoda: Entognatha) inhabit interstitial sediments and soils on the island (Lima and Zeppelini, 2015; Palacios-Vargas et al., 2013). They can carry organic and inorganic particles in the same size range as SMP particles within sediment layers, so there is the potential for them to also transport those SMP that would then be available to other organisms in the sediment (Maaß et al., 2017). If ingested, SMP may decrease the feeding and locomotion capacity of organisms through physical or chemical (persistent organic pollutants and heavy metals) effects (Besseling et al., 2013). Also, as organisms in the benthos support organisms in higher trophic levels, the availability of SMP may introduce these particles in the trophic web and have unknown consequences on the insular ecosystem.

Although the ingestion of fibres has been reported for organisms in different levels within marine food webs, there are very few insights related to the preferential colour that is ingested. Fibres samples in this study were mainly blue and/or black, which fit with most of the fibres that were previously reported to be ingested by polychaetes in the Atlantic and Mediterranean seas and were also in the same size range (i.e. 2–4 mm) (Gusmão et al., 2016). Moreover, blue and black fibres (77%) were also reported to be prevalent over other microplastic particles ingested by the Atlantic ghost crab (Costa et al., 2019). Based on the results presented here, there is a real potential of ingestion of fibres deposited on sandy beaches. Endemic, resident, and migratory species on the island are at imminent risk of microplastic ingestion.

CONCLUSION

The presence of SMP pollution on Fernando de Noronha Island, which is a hotspot of marine biodiversity, was confirmed for the first time. Future studies about (micro)plastic pollution should consider meteorological and oceanographic forcing, seasonality, beach morphodynamics, and anthropogenic influences to allow the understanding of the accumulation and removal processes of SMP in the beaches of Fernando de Noronha Island. Finally, island managers should determine ways to prevent and remediate the plastic pollution on the island to ensure a healthy marine ecosystem for future generations, such as the District Decree N° 002 approved in December 12th, 2018 that provides for the prohibition of single-use plastics in the island.

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