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Occurrence and characteristics of microplastics on insular beaches in the Western Tropical Atlantic Ocean

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Abstract

Microplastics are widespread throughout oceans and seas and beaches are no exceptions. On beach sediments, microplastics (<5mm) are commonly prevalent over macroplastics (>5mm), where fragments of larger items are sampled in greater amounts. The occurrence and characteristics of microplastics were investigated on beaches of Fernando de Noronha, Abrolhos and Trindade islands located in the western tropical Atlantic Ocean. Despite no microplastic was identified in Abrolhos at this time, small spatial variations were detected in Fernando de Noronha and Trindade islands, highlighting the importance of oceanographic variables on plastics distribution and accumulation over time.

Keywords: Blue Amazon, oceanic islands, marine conservation, plastic fragments, virgin plastic pellets, size class.

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Introduction

On beaches, macroplastics degrade and finally fragment into smaller pieces (i.e., secondary sources), being fragments and fibres finally incorporated into coastal sediments (Barnes et al., 2009). Field data confirm that microplastics (< 5mm) are an abundant size fraction within plastic debris pollution (e.g., Browne et al., 2011). They are widespread throughout oceans and seas (e.g., Depledge et al., 2013; Ivar do Sul and Costa, 2014), including deep-sea sediments (Cauwenberghe et al., 2013) and far from obvious sources of plastics. Virgin plastic pellets and other particles manufactured to be of a microscopic size (i.e., primary sources) are also incorporated to beach sediments after storm-water discharges and direct spills into the sea (e.g., McDermid and McMullen; 2004, Fendall and Sewell, 2009).

Microplastics are much more hazardous than macroplastics to marine organisms because they are available to all levels of marine food webs though ingestion (Wright et al., 2013). They are also more efficient in the transport of adsorbed organic and inorganic contaminants to remote areas, and potentially contaminate organisms once ingested (Tanaka et al., 2013).

Microplastics have been sampled on beach sediments through different methods, most focused on their recent deposition on the beach face (e.g., Barnes et al., 2009; Hidalgo-Ruz et al., 2012). On mud sediments around industrialised areas, fibres are been commonly related to sewage and wastewater discharges (Browne et al., 2011). On the other hand, in oceanic islands, sandy beaches are frequently reported to be heavily impacted by ocean-borne plastics in the same size range of sediments, mainly in the Pacific Ocean (McDermid and McMullen, 2004; Moore, 2008; Hidalgo-Ruz et al., 2012). In the Atlantic Ocean, fragments and pellets, originated far from their sources, were sampled on sandy beaches in the Fernando de Noronha archipelago (Ivar do Sul et al., 2009). Therefore, it is expected (Barnes et al., 2009; Ivar do Sul and Costa, 2014) that this type of marine debris pollution currently contaminates other insular beaches in the western tropical Atlantic Ocean, but the extent of the problem is still unknown.

The present study investigated, for the first time, the assessment of microplastic contamination (occurrence and physic characteristics) on beaches in the Abrolhos archipelago and Trindade island, in the tropical western Atlantic Ocean (Figure 1A), including a sample re-purposing in the Fernando de Noronha archipelago. Different aspects related to microplastic debris contamination were assessed and discussed.

Material and Methods

A total of 20 beaches were surveyed once in Fernando de Noronha (3°S, 32°W) (13 beaches), Abrolhos (17°S, 38°W) (3 beaches) and Trindade (20°S, 29°W) (4 beaches) islands during the austral summer season (2011/2012, 2012/2013). One sediment sample (80 g) was collected in the centre of the beach arc to grain size characterization. The dry sieving method and the Folk and Ward (1957) classification were applied in this study (Table 1).

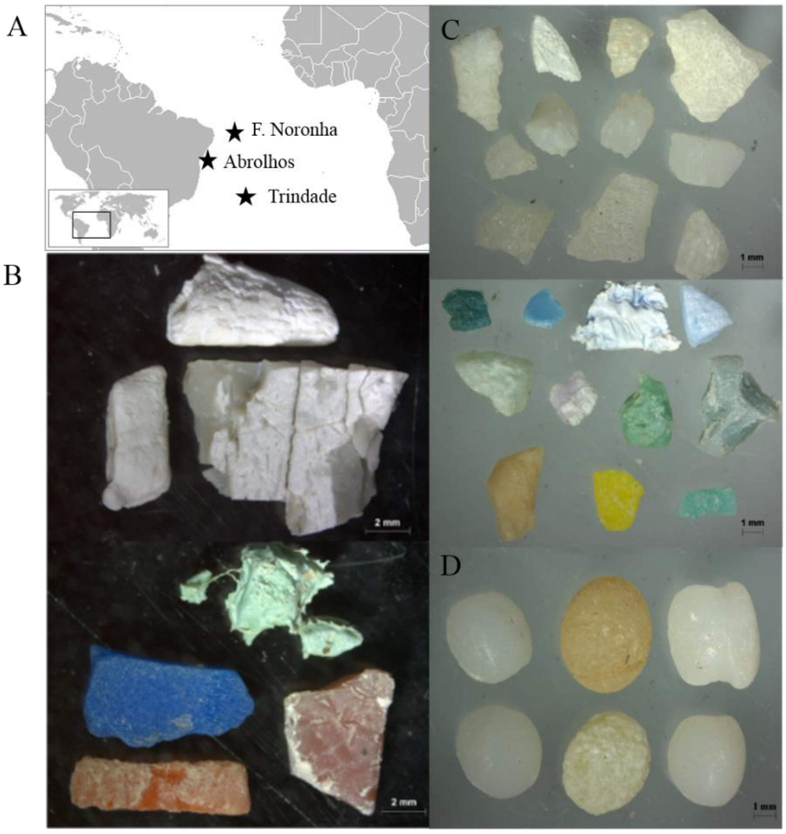

Figure 1: (A) Studied islands in the western tropical Atlantic Ocean: Fernando de Noronha, Abrolhos and Trindade. (B) Examples of white and coloured macroplastic (>5mm) fragments. (C) Examples of white and coloured microplastic fragments and (D) virgin plastic pellets. All images were obtained with the AxioVs40 V 4.8.2.0 software from Carl Zeiss Vision.

In the tropical western Atlantic Ocean, the circulation of the atmosphere (i.e., southeast trade winds and the westerlies) primarily drives the upper ocean large-scale circulation in the southern hemisphere. The nearest oceanic moorings (http://www.pmel.noaa.gov/pirata/) were used to classify the sampled beaches into two groups: windward (9) and leeward (11) beaches, according to the prevailing winds in each island (see Ivar do Sul et al., 2014 for details) (Table 1).

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Table 1: Sampled beaches in Fernando de Noronha (350 km from the continent), Abrolhos (70 km from the continent) and Trindade (1,100km from the continent). Beaches are classified according to the prevailing winds in the area (LW=leeward; WW=windward). The approximate length of each beach and sediments characteristics are also presented.

		Beach	Length (m)	Sediments characteristics: Main grain size	Classification of sorting	Skewness
FERNANDO DE NORONHA	LW	Sancho	500	Fine sand	Good	Near symmetrical
		C. do Padre	500	Fine sand	Good	Near symmetrical
		Bode	350	Fine sand	Good	Near symmetrical
		Americano	200	-	-	-
		Boldró	700	Fine sand	Good	Near symmetrical
		Conceição	220	-	-	-
		Meio	100	Fine sand	Good	Near symmetrical
		Porto	200	Fine sand	Good	Coarse
		Air France	250	Medium sand	Good	Near symmetrical
	WW	E. dos Tubarões	85	Fine sand	Good	Coarse
		Atalaia	100	Medium sand	Moderate	Near symmetrical
		Sueste	510	Medium sand	Poor	Coarse
		Leão	540	Medium sand	Moderate	Coarse
ABROLHOS	LW	Caldeiras	100	Fine sand	Moderate	Coarse
	WW	Santa Bárbara	100	Coarse sand	Good	Near symmetrical
		Redonda	150	Coarse sand	Good	Near symmetrical
TRINDADE	WW	Cabritas	350	Medium sand	Moderate	Near symmetrical
		Tartaruga	200	Medium sand	Moderate	Near symmetrical
		Parcel	200	Coarse sand	Moderate	Near symmetrical
	LW	Príncipe	200	Coarse sand	Good	Near symmetrical

For microplastic survey, the strandline (1m wide) was sampled by scraping the two first centimetres of sand from 900cm^2 quadrats, a well-established protocol to monitor microplastics on beaches (Ivar do Sul et al., 2009). Three quadrats were thrown along the strandline on each surveyed beach, in a total of 60 samples. Sediment samples then were taken to the laboratory where they were oven-dried at 100°C overnight. The dry samples were weighted and sieved through a 0Φ (1mm) sieve to guarantee the accuracy on microplastic identification. Only the upper (>1mm) sub-samples were analysed. Two types of plastics were identified and classified as hard plastic fragments and virgin plastic pellets (Figure 1D, E). Individual items were then sorted by size class and colour, measured and photographed. All images were obtained with the AxioVs40 V 4.8.2.0 software from Carl Zeiss Vision.

Density of plastics particles was expressed as particles per square meter (particles/m²) of sand. Two hypotheses were tested with the Factorial Analysis of Variance (ANOVA): (1) windward beaches are significantly more contaminated than leeward beaches and; (2) types of microplastic particles are recurrent among the studied islands, but hard plastic fragments are prevalent. Data was transformed (Box-Cox transformation) to achieve normality, whilst homoscedasticity was tested with Levene's test. Where ANOVA showed a significant difference, an *a posteriori* Fisher LSD test was used to determine which mean was significantly different (α=0.05).

Results and Discussion

In this study, the occurrence of microplastics on insular beaches in the western tropical Atlantic Ocean was confirmed for the first time in the Trindade island (Figure 1). In the Abrolhos archipelago, however, no plastic particle was sampled at this time. The occurrence of microplastics on sandy beaches in the Fernando de Noronha archipelago was once again confirmed, showing this is probably a chronical type of marine pollution in the archipelago.

A total of 1,151 plastic particles were sampled in this survey. Twenty-three quadrats (40%) in 12 beaches (60%) were contaminated (Table 2). In the Trindade island, three beaches were contaminated, but no plastic particle was sampled on Príncipe beach (leeward side). In Fernando de Noronha, five beaches were free from plastics; a single fragment was sampled on three beaches; and five other beaches presented higher contamination rates (Table 2).

Quantitatively, windward beaches were more contaminated by plastic particles than the leeward beaches when all sampled beaches were considered, corroborating hypothesis 1. This result confirmed the direct influence of surface currents and winds in the transport of initially buoyant plastics in the open ocean (i.e., Ivar do Sul et al., 2009). On the other hand, the absence of microplastics in Abrolhos Island during this survey is probably due to the beach sedimentary budget, which may remove all the sand, and consequently plastics, from beaches. This process is cyclical, and may underestimate

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microplastic sampling in a specific time. Systematic monitoring of those beaches are necessary to confirm this pattern.

Table 2: Microplastic particles sampled in Fernando de Noronha and Trindade islands. LW=leeward beaches and WW=windward beaches. In Abrolhos, no microplastic particle was sampled. Beaches are listed according to island, relative position and main grain size.

				Hard fragments		Pellets					
				White	Colour	White	Colour	Total	Mean (±Stdev)		Particles / m²
Fernando de Noronha	LW	Fine sand	Sancho	0	0	0	0	0	-	-	0
			C. do Padre	0	0	0	0	0	-	-	0
			Bode	1	0	0	0	1	0.33	(±0.5)	1.23
			Americano	0	0	0	0	0	-	-	0
			Boldró	0	0	0	0	0	-	-	0
			Conceição	1	0	0	0	1	0.33	(±0.5)	1.23
			Meio	0	0	0	0	0	-	-	0
			Porto	4	0	0	0	4	1.33	(±2)	4.94
	WW	Medium sand	Air France	3	0	0	0	3	1	(±1.5)	3.70
			Tubarões	45	0	32	0	77	25.67	(±22.8)	95.06
			Atalaia	20	7	21	7	55	18.33	(±7.8)	67.90
			Sueste	1	0	0	0	1	0.33	(±0.5)	1.23
			Leão	3	0	2	2	7	2.33	(±1.3)	8.64
Trindade	WW	Medium sand	Cabritas	194	14	121	43	372	124	(±81.1)	153.09
			Tartaruga	212	5	133	39	389	129.67	(±93.7)	160.08
			Parcel	147	40	41	9	237	79	(±60.4)	97.53
	LW	Coarse sand	Príncipe	0	0	0	0	0	-	-	0

In the islands of Fernando de Noronha and Trindade, mean densities of microplastics were lower than in the Eastern Island (805 items/m²), which was significantly more contaminated than other beaches along the Chilean coast (Hidalgo-Ruz and Thiel, 2013). The Eastern Island is close to the eastern-centre region of the South Pacific subtropical gyre, where pelagic plastics are showed to accumulate (Lebreton et al., 2012), showing that oceanic islands act as depositional sites for pelagic microplastics at sea (Moore, 2008; Hidalgo-Ruz and Thiel, 2013). On Trindade windward beaches, however, densities reached the same order of magnitude than in the South Pacific Ocean (Hidalgo-Ruz and Thiel, 2013). Since this island is far from (1,100km) the shore, ocean-borne plastics may be prevalent over land-based sources of plastic debris.

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Characteristics of microplastic particles

Microplastics have an average size of 3.72±2.21 mm in this study. Only two types of plastics were identified (i.e., hard plastic fragments and pellets) showing that types of items are recurrent in the tropical Atlantic (Ivar do Sul et al., 2013; Ivar do Sul et al., 2014). In terms of number of items, hard plastic fragments (Figure 1C) accounted for 60% of all sampled microplastics (n=697). The numerical dominance of hard plastic fragments over virgin plastic pellets (Figure 1D) is a predicted trend, according to the literature, in the Pacific (Kushio and Noda, 2003; McDermid and McMullen, 2004; Hidalgo-Ruz and Thiel, 2013; Moore 2008) and Atlantic oceans (Browne et al., 2010). However, densities (particles/m^2) of hard plastic fragments were not significantly different than pellets (p=0.416) in the islands, so the hypothesis 2 was not corroborated.

Fibres and strands (Ivar do Sul et al., 2014) were absent during this survey. In the North Sea, fragments were completely absent whereas fibres and pellets were systematically sampled on the sediment surface of coastal islands (Liebezeit and Dubaish, 2013). Moreover, synthetic fibres are being related to sewage discharges, including washing machine effluents and mainly around high-populated areas (Browne et al., 2011). The absence of fibres and the occurrence of plastic pellets may indicate that marine-based sources are dominant when compared with sewage discharges (e.g., Claessens et al., 2011; Hidalgo-Ruz and Thiel, 2013). However, sub-samples <1mm need also to be investigated in relation to the relative proportion of fibres and fragments.

In this study, white and transparent plastic particles were prevalent (75%) as previously observed in adjacent ocean areas (Ivar do Sul and Costa, 2014). The colour distribution may be an indicator of the residence time of the plastic on beach environments (i.e., discolouring), which is the most likely site for degradation and consequently fragmentation of microplastics in the marine environment (Andrady, 2011).

Conclusion

This study highlights the widespread occurrence of microplastics in marine ecosystems, especially considering that those islands are far away from direct sources of land-based contamination (e.g., rivers, drainage systems), which are plastic hotspots.

Spatial variation in microplastic densities was observed on a relatively small scale (distance of few km) in Fernando de Noronha and Trindade. This may be due to different current patterns, grain size, wave action and wind exposure of each beach. All beaches are isolated from obvious plastic debris sources (i.e., dense human population centres, plastic facilities). Then, it is most likely that plastics came from the adjacent marine area, where ships and fishing boats generate pelagic plastics, which are recognized sources of plastic debris to the marine environment (e.g., Andrady, 2011; Ivar do Sul and Costa, 2014).

Beyond the already established effects of ingestion, chemical leaching, and contaminant adsorption (e.g., Moore, 2008), plastic pellets and fragments may change the physical properties of beaches by increasing permeability and lowering subsurface temperatures (~1°C) (Carson et al., 2011). This can affect the sex of temperature-determinant organisms, such as sea turtles (e.g., a reduction in the number of females). Bioturbation of sediments on sea turtles nesting areas may also redistribute microplastics along the surface layer (1m), underestimating the amounts of sampled plastics. These might affect the quantification of beach plastics in Trindade and Fernando de Noronha since these islands are important nesting areas for *Chelonia mydas*.

Currently, the most widely used (~90%) synthetic plastics are low- and high-density polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS) and polyethylene terephthalate (PET) (Andrady, 2011). Polymer types have been successfully identified in sediment samples by FTIR and other techniques (e.g., Browne et al., 2010, 2011), including pellets (e.g., Fotopoulou and Karapanagioti, 2012). Eroded PE pellets had their surface areas enlarged, indicating that they will interact more efficiently with chemical compounds in the marine environment (Fotopoulou and Karapanagioti, 2012). Microplastic fragments will probably follow the same pattern, representing greater risks to organisms through ingestion since physical and chemical contamination will occur synchronically.

Recently, new methods to sample, quantify and/or identify microplastics on sediments have been developed by several research groups. Since a range of different methods have been applied, a direct comparison of data from different studies is rare. Thus, a precise and comprehensive diagnosis of microplastic contamination on sedimentary habitats remains to be done.

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