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# A Comprehensive First Baseline for Marine Litter Characterization in the Madeira Archipelago (NE Atlantic)

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**Abstract** Marine litter is currently worldwide distributed, and plastic is its principal component. Nevertheless, to date, little is known about how this global threat is affecting the marine coastal areas of the Madeira archipelago (NE Atlantic). In this context, we conducted the first comprehensive survey for marine litter characterization in the region, by addressing micro-litter (0.010–5 mm), meso-litter (5–25 mm) and macro-litter (> 25 mm). Our results confirmed that the marine litter issue in Madeira Archipelago is well aligned with what is occurring in other global regions, and plastic is the major component of marine litter, with "plastic-polystyrene" being the most common macro-litter category found. Finally, the different protection status of the sampling areas shows some differences regarding the quantity of macro-litter present as litter abundance in a Marine Protected Area located in the north coast of Madeira has registered lower abundances.

**Keywords** Marine litter · Madeira Island · Plastic · Microplastic · Macro litter · Island ecosystem

## 1 Introduction

Plastic litter is currently a significant threat to the marine environment (Derraik 2002) because, but not exclusively, of its longevity and the disposable nature of every plastic item (Thompson et al. 2004). The scientific community started to refer this global problem back in the 1970s (Carpenter et al. 1972; Carpenter and Smith 1972; Colton et al. 1974; Fowler 1987), and it has been highly debated in recent years (Deudero and Alomar 2015; Hartley et al. 2018; Villarrubia-gómez et al. 2017). A considerable amount of plastics, metals, rubber, paper, textiles and fishing gear are discarded into the marine environment every day, making anthropogenic marine debris (AMD) one of the most extensive pollution problems our planet is facing today (Rochman et al. 2015). The majority of marine litter present in the ocean is plastic (Eriksen et al. 2014; Jambeck et al. 2015), whether found floating at the ocean surface, beaches or seafloor (Law 2017). A total of 348 millions of tons of plastic were produced globally in 2017 alone (PlasticEurope 2018) and plastic production increases every year due to its low cost, versatility, low weight and resistance (Andrady 2011). Specifically, its abundance,

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durability and persistence are a particular concern to marine environment conservation (Gall and Thompson 2015). For example, several recent studies on the diet of marine animals have confirmed a regular plastic ingestion (Nelms et al. 2019); furthermore, modelling techniques predicted plastic ingestion in 99% of world's seabirds by 2050 (Wilcox et al. 2015). Plastics have also been found in fishes and shellfishes diet to human consumption (Rochman et al. 2015) and are affecting other marine species like turtles, seabirds and marine mammals (Gregory 2009; OSPAR 2009). Entanglement is also a significant problem occasioned by marine anthropogenic debris that originate from discarded fishing gear (Derraik 2002). In addition, plastic is being used also as nesting material for seabirds (Hartwig et al. 2007) and some preferences were observed for ropes made from synthetic fibres (Votier et al. 2011) and rubber (Verlis et al. 2014). The spread and ubiquity of marine litter is such that nowadays even seabirds can be used as indicators to monitor this marine pollutant in remote areas using a cost-effective approach to evaluate this kind of pollution over a large and disperse geographic area (Provencher et al. 2015).

Furthermore, with the mass production of plastic initiated in the 1940s, microplastics contamination has also became a real concern (Cole et al. 2011). These microplastics are small plastic particles usually smaller than 5 mm that are originated either from manufacturing as primary or from the breakdown of larger plastic debris items by the action of physical, biological and chemical processes (Cole et al. 2011). This type of micro-litter is also ubiquitous, especially microfibers (Gago et al. 2018). Micro-litter can have additional negative consequences for marine biota as it can act as a vector for heavy metal contamination transferring this toxicity to marine communities (Brennecke et al. 2016) and also introducing persistent organic pollutants (POPs) into marine organisms (Hirai et al. 2011; Rios et al. 2007; Teuten et al. 2009).

In this context, the European Commission has considered necessary to implement a new governmental legislation to protect the marine environment and in 2008 approved the Marine Strategy Framework Directive (MSFD) (Europe Union 2008) with the main objective of protecting more effectively the marine environment across European waters. The MSFD is considered the first EU legislative instrument to protect marine biodiversity and has established a total of 11 Qualitative Descriptors as tools to define the Good Environmental Status (GES). The 10th descriptor, focused exclusively on marine litter, determines a GES of the seas when properties and quantities of marine litter do not cause harm to coastal and marine environments (Europe Union 2008).

Furthermore, Portugal has one of the largest Exclusive Economic Zone (EEZ) in Europe with more than 1.6 million km$^2$ (Direção-Regional de Recursos Naturais Segurança e Serviços Marítimos 2018), making marine environment management of the country an important future challenge. In this context, the Madeira archipelago is located in the north-eastern Atlantic Ocean within the Macaronesia ecoregion (Spalding et al. 2007) and 700 km away from the African continent. This offshore archipelago is oceanographically affected by a complex of oceanic and coastal currents, where three major currents (the Canary, the Azores and the Portugal currents) interact (Barton 2001; Caldeira et al. 2002) meeting the cold temperate waters from the north and the warm tropical waters from the south (Caldeira et al. 2002), and making the archipelago as a possible location for the development of monitoring programs for oceanic marine debris (Sala et al. 2016). In fact, some recent studies focused on the Canary Islands (located at approximately 500 km south of Madeira) confirmed the existence of marine plastic pollution and corroborated that microplastic pollution is originated from the open ocean (Baztan et al. 2014; Herrera et al. 2018a). These studies also suggested that litter accumulation depends mainly on coastline orientation as well as local-wind and wave conditions (Herrera et al. 2018a).

In addition, wastewater treatment facilities are known to contribute to microplastics removal from local effluents, but if these effluents are large volumes, it can also facilitate the entering in the environment (Murphy et al. 2016). Some studies refer that populated areas or habitats that received sewage have more density of synthetic fibres (Browne et al. 2011). In Madeira archipelago, there are a total of 18 active wastewater treatment stations with different levels of treatment and volume capacity (Correia Machado 2016).

In this context, the main goal of the present study was to report the first baseline inventory on marine litter in Madeira Archipelago. In particular, this study was designed to (1) evaluate the presence of macro-, meso- and micro-litter on the coastline of the Madeira Archipelago and (2) characterize the composition and size range of marine litter across different coastal local environments.

## 2 Material and Methods

### 2.1 Study Sites

The study was performed in the two major inhabited islands of the Madeira archipelago i.e. Madeira and Porto Santo Island located between 32° 37′ to 33° 7′ N and 16° 16′ to 17° 15′ W, both separated by approximately 40 km (Fig. 1). Different natural locations were selected along the coastlines of Madeira and Porto Santo islands. Four pebble beaches in Madeira were selected to sample macro-litter (two in the north and two in the south coast), whereas meso- and micro-litter were sampled in five different sandy beaches (due to the requirements of the protocol implemented), four in Madeira (two in the north and two in the south coast) and one in Porto Santo, but presenting similar environmental conditions to pebble locations (Fig. 1).

### 2.2 Sampling Protocol

Following MSFD recommendations, this study established three different sampling size categories of marine litter: micro- (0.010–5 mm), meso- (5–25 mm) and macro-litter (> 25 mm) (MSFD Technical Subgroup on Marine Litter 2013).

#### *2.2.1 Macro-Litter Sampling*

Sampling surveys for macro-litter were conducted in four different sites, two located in the North Coast of Madeira Island: Seixal (S) and Rocha do Navio (RN); and two others in the South coast: São Lourenço (SL) and Reis Magos (RM) (Fig. 1), with apparently different hydrodynamic processes (Caldeira et al. 2002). Specifically, Rocha do Navio study site is located in a classified area as Marine Protected Area (MPA), and São Lourenço in a protected terrestrial area inside the Madeira Nature Park and included in the Natura 2000 network as a Special Area of Conservation (SAC) and Special Protection Area (SPA). Seixal and Reis Magos have not any legal status for extra protection and conservation. The shoreline at each of these sites was sampled by employing the OSPAR methodology for 100-m transects, and the items were classified according on it (OSPAR Commission 2010). Taking the tides as a reference, we sampled 4 equal parallel transects to the coastline: low, medium, high and splash (corresponding all of them between low tide and the line just above the high tide line). All litter items larger than 25 mm found in the 100-m transect were collected, counted and weighted. This sampling procedure was repeated at three different periods (i.e. April, May and July, 2017) and was considered replicates to assess the accumulation and influx of macro-litter between sites.

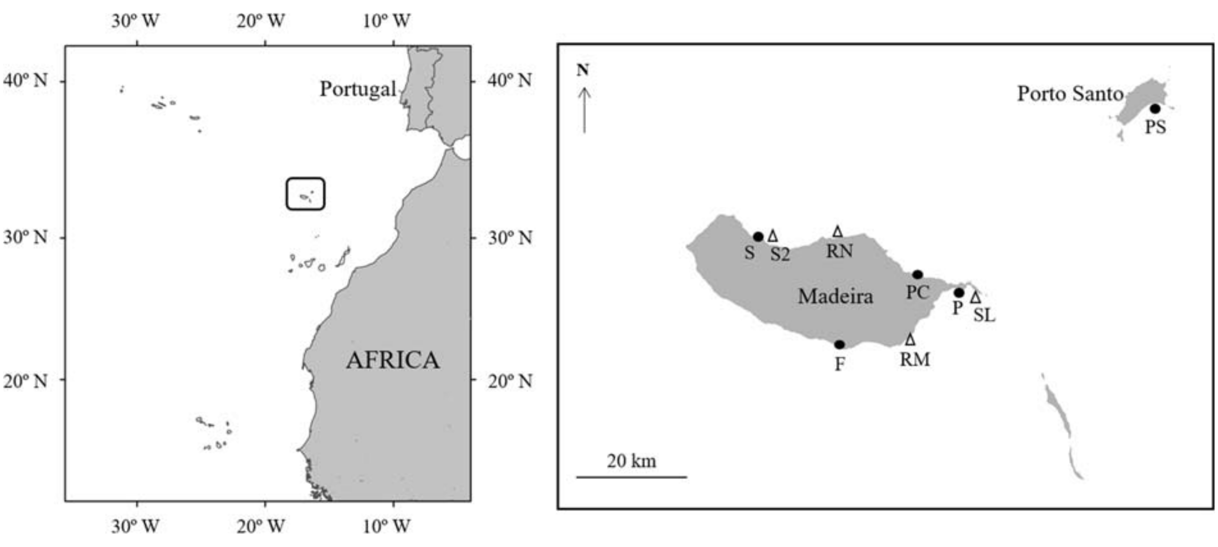


**Fig. 1** Map of the Madeira Archipelago with the locations of the marine litter sampled sites: Seixal (S), Seixal2 (S2), Rocha do Navio (RN), Porto da Cruz (PC), Prainha (P), São Lourenço (SL), Reis Magos (RM), Formosa (F) and Porto Santo (PS). Macro-litter sampled sites are shown by open triangles and micro- and meso-litter sampled sites are shown by filled circles

*2.2.2 Micro and Meso-Litter Sampling*

In Summer 2017, micro and meso-litter samples were collected, from five different sandy beaches (i.e. study sites): Seixal2 (S2), Porto da Cruz (PC), Prainha (P), Formosa (F) and Porto Santo (PS). All sites, except PS, are located in Madeira Island, S2 and PC in the North coast, and P and F in the South coast. The PS study site is located in the South coast of Porto Santo Island (Fig. 1). The method of identification and classification of micro- and meso-litter followed the Guidance on Monitoring of Marine Litter in European Seas (MSFD Technical Subgroup on Marine Litter 2013) with some adaptations (Herrera et al. 2018a). For litter larger than 1 mm, 3 replicates were collected from each study site. Replicates were taken from a square of 50 × 50 cm (0.25 $m^2$) randomly deployed along the high tide line in the accumulation area of each study site. A volume equivalent to one litter of sand was collected from the top of the square and introduced in a net bag with 1-mm pore size. The bag was then closed and washed with seawater. As a result, the sample > 1 mm remained trapped inside the net bag (Herrera et al. 2018c).

All collected samples were dried for 24 h at 60 °C in an oven (VWR DL53), and then 96% ethanol was added to samples to separate the organic material by density (Herrera et al. 2018b). Samples were dried again and passed through a 5-mm sieve to separate micro-litter from meso-litter. All samples were weighted in a high-precision scale (Practum® - Sartorius), and all litter items were counted using a stereomicroscope (Leica S8APO).

To identify micro-litter smaller than 1 mm size, three subsamples were taken from the same site, each containing 50 ml of sediment. Each sample was then mixed with 200 ml of a concentrated saline solution of NaCl (1.2 g $cm^{-3}$), stirred for 2 min and left undisturbed for 1 h. Later, the supernatant was sieved through an aperture of 0.2 mm and then transferred to a suction filtration system passing through polycarbonate filters of 0.010-mm pore size (Herrera et al. 2018c). This procedure was performed three times for each subsample, and then filters were carefully examined under a Leica S8 APO Stereomicroscope for items counting. Items from the three filters were then pooled as they represent a single subsample.

All litter items, from 0.010 to 25 mm, were classified according to Annex 8.1 of the Guidance on Monitoring of Marine Litter European Seas (MSFD Technical Subgroup on Marine Litter 2013). In addition, as performed in previous studies (Gallagher et al. 2016; Matsuguma et al. 2017; Syakti et al. 2017), all litter items were also categorized by colours in order to identify the different likelihood of ingestion or bioavailability since some marine individuals can confuse plastic items with preys within similar colour (Wright et al. 2013). The amount of items were then standardized as items/$m^2$, items/L, items/Kg, g/$m^2$ and g/L in order to allow comparisons with previous studies (Herrera et al. 2018a; Lozoya et al. 2016; Tsang et al. 2017). For the purpose of the comparative analysis, items/L was selected as a measure unit. To minimize possible accidentally contamination of samples, all materials and equipment used during sampling and laboratory analyses were previously washed. In addition, glass containers were used for sediment sampling. Finally, all team members involved in both sampling and laboratory procedures were wearing white cotton laboratory clothes.

## 2.3 Data Analysis

Univariate and multivariate analyses were used to test for differences in the overall patterns of accumulation of both major litter sizes (macro and micro-meso) across the study sites sampled in 2017. Similar methodological analyses to those used in community ecology were applied here by considering litter categories as analogies of species (i.e. in those community ecology studies). This approach was intended to facilitate the comparison, evaluation and interpretation of marine litter accumulations.

Differences in macro-litter diversity (OSPAR Commission 2010) and macro-litter total abundance were analysed using multivariate analysis of variance (PERMANOVA), based on Euclidean distances (Anderson 2005, so resulting F ratio is the same as the F statistic of traditional ANOVA), with two orthogonal factors: site (4 levels: Rocha do Navio (RN), Seixal (S), Reis Magos (RM) and São Lourenço (SL); fixed) and height (4 levels: low, medium, high and splash; fixed) ($n = 3$). Differences in the composition of macro-litter accumulations were analysed with the same design but conducted on PERMANOVA analysis run on a Bray-Curtis similarity matrix based on square-root transformed count data considering all the macro-litter OSPAR categories and the $p$ values related to the pseudo-$F$ ratios were calculated by permutation raw data through 9999 random permutations (Underwood

1997). Patterns of accumulation of micro- and meso-litter were also analysed by using the same multivariate techniques. The model included only one orthogonal factor Beach (Be, 5 levels: Porto Santo (PS), Formosa (F), Porto da Cruz (PC), Prainha (P) and Seixal2 (S2); fixed).

Whenever there were only a few possible permutable units to get a precise test, approximate *p* values were estimated by Monte Carlo method (Anderson and Robinson 2003). When significant differences ($p < 0.05$) among factors or their interactions were observed, post hoc pairwise tests were performed. Additional nMDS were elaborated to graphically visualize multivariate patterns of variation in two dimensions, showing the accumulation patterns of different marine litter categories. Types of litter that contributed the most to the similarity within sites were identified using SIMPER analysis (Clarke 1993). All analyses were performed using the software PRIMER version 6.1.13 (Clarke and Gorley 2006) with the add-on PERMANOVA + version 1.0.3 (Anderson 2005).

## 3 Results

### 3.1 Macro-Litter

A total of 52 different types of macro-litter items (OSPAR Commission 2010) were found across all study sites. Of these, "plastic-polystyrene", one of the main categories from the OSPAR methodology that includes all types of plastics, was the most abundant type of litter found in all study sites and across all tidal heights, accumulating more than 80% of the total amount of items (Fig. 2). The most common items found across all sites were "plastic 2.5–50 cm" (46.3%), "plastic drink containers" (10%), "caps/lids" (4.5%), "crisp/sweet packets/lolly sticks" (3.3%) and "plastic bags" (1.6%). In total, more than 51 kg were collected from all study sites, and plastic-polystyrene alone represented more than 26 kg.

There were significant spatial effects in the accumulation of the macro-litter at both large (i.e. between sites) and small scales (i.e. between heights in the shore) (Table 1). Diversity and abundance of macro-litter accumulations were significantly lower in Rocha do Navio (RN) when compared with other sampled sites except in Seixal (S) (Fig. 3). Here in S, also located in the north coast of Madeira, macro-litter abundance was also lower but not statistically significant from those found in RN (Fig. 4a, b). With regard to tidal heights, low and medium intertidal levels accumulated similar diversity and abundance of macro-litter. In both cases, litter diversity and abundance values were lower than the two upper levels (i.e. high and splash), and the differences between medium and high levels were not significantly different. Maximum accumulation of macro-litter was always found at the splash level (Fig. 4c, d). Total composition of macro-litter accumulation was also significantly affected by the small and large spatial variability included in our study (Fig. 5a, b). Similarly to the univariate patterns, the composition of the accumulated macro-litter was significantly different in RN when compared with study sites located in the south coast of Madeira, but similar to the litter accumulated in S (Pairwise tests, *p* (perm) < 0.05; (Fig. 5a). SIMPER analysis confirmed "plastic/polystyrene 2.5–50 cm" as the most abundant macro-litter item across all sites and shore height levels (SIMPER, Fig. 3). Macro-litter accumulations in RN were particularly characterized by the presence of high abundances of crisp/sweet packets/lolly sticks and "industrial scrap" as the second and the third more abundant items, respectively (SIMPER, Fig. 3). At the S study site, aside from the most abundant item, plastic/polystyrene 2.5–50 cm, it was remarkable the presence of plastic bags and also "other woods < 50 cm" as third and fourth most abundant litter item, which were inexistent at the remaining study sites, with the only exception of RN and SL where plastic bags and other woods < 50 cm were found in very low abundances. The litter accumulations on the RM site were particularly characterized by the high abundances of metals and also by the almost exclusively presence of "other rubber pieces". Finally, SL litter accumulations were overall more diverse in composition and especially characterized by the presence of items quite common to the other sites (i.e. "food containers", "drinks (bottles, containers and drums)", cap/lids, "other plastic") but also by the contribution of several exclusively items that, although in a low abundance, were only found at this particular site (i.e. "string/cord", "foam sponge") (SIMPER, Fig. 3). Litter composition was also affected by the height in the shore (Table 1). The accumulation found in the splash zone was significantly different from those collected in the lower levels (Pairwise tests, *p* (perm) < 0.05; Fig. 5b). There were also significant differences between the macro-litter collected from low and high levels whereas the medium level was a transition area being similar to

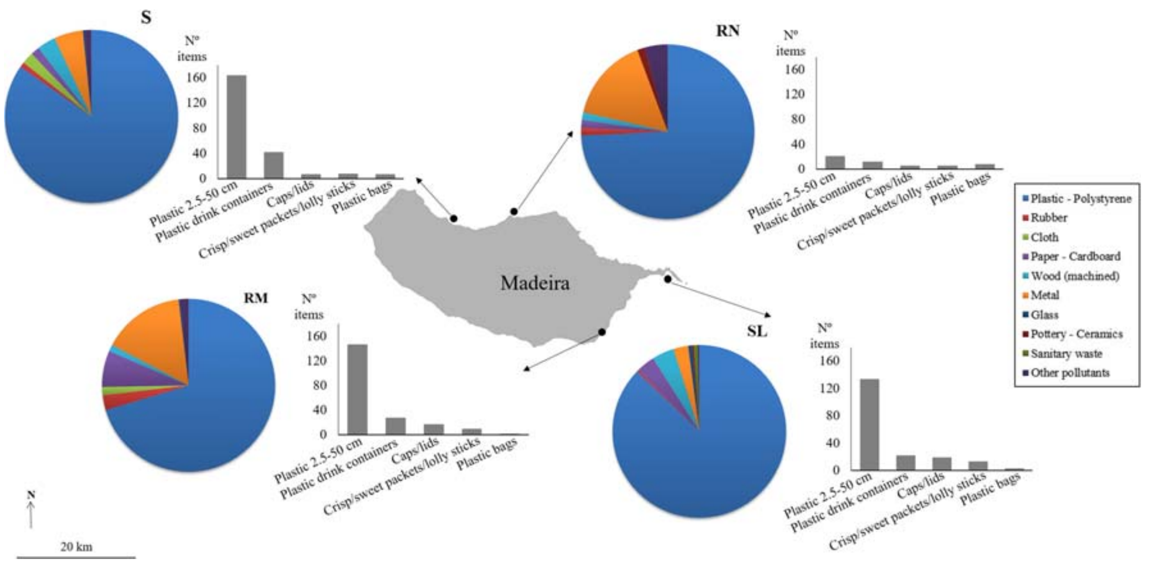


**Fig. 2** Proportion of items of macro-litter found in the four sampled study sites: Seixal (S), Rocha do Navio (RN), São Lourenço (SL) and Reis Magos (RM). Patch arts represent the percentage found in each OSPAR category; histograms represent the quantities of common items in all sites within the plastic-polystyrene category

both levels (Fig. 5b). The accumulation of macro-litter by height in the shore was also characterized by a large contribution of plastic/polystyrene 2.5–50 cm, which was the most common item in all tidal heights (SIMPER, Fig. 3). Overall, there was an increase with the presence of different plastics (crisp/sweet packets/lolly stick; caps/lids; plastic drink containers and plastic food containers), metal (industrial scrap and other metal pieces < 50 cm) and wood items (other woods < 50 cm) in the medium and high heights. The maximum amount of different types of items was in the splash level where a total of 9 different types of plastics were responsible to characterize the level (SIMPER, Fig. 3). In this level also "cartons/tetrapak" and "other" were characterizing items.

### 3.2 Micro-Litter and Meso-Litter

The accumulation of the smallest fraction of micro-litter (0.010–0.200 mm) ranged between 306 and 920 items/L on the beaches of PC and S2, respectively (Fig. 6a). Marine litter between 0.200 and 1 mm was only found in S2 and F (Fig. 6b). For micro-litter larger than 1 mm, PC and F were the sites with more accumulation, with more than 8 and 26 items/L, respectively (Fig. 6c). Finally, Formosa also showed the highest meso-litter accumulation (Fig. 6d).

The diversity and abundance of micro/meso-litter accumulation differed significantly across the different sampling sites (Table 1). Formosa study site contained higher number of different items, although this higher diversity was only significant in comparison with PS and P (Pairwise tests, P (MC) < 0.05; Fig. 7a). In contrast, PS and P showed lower diversity of micro/meso-litter and S2 and PC accumulated similar intermediate values (Fig. 7a). Abundance of micro/meso-litter items collected from the sandy beaches did not differ significantly between study sites (Table 1). However, there was a tendency of lower quantities in PC and P and maximum accumulation in S2 (Fig. 7b). According to the total composition of the litter found, there were significant differences between sites (Table 1). In particular, the micro/meso-litter accumulated in the sand of F was significantly different to those accumulated on S2 (Pairwise tests, P (MC) < 0.05; nMDS Fig. 8). In contrast, litter accumulation in PS, P and S were similar, and although not significant, there was a tendency to differ from those collected in F and PC as the segregation in the nMDS showed (Fig. 8).

The smaller fraction of micro-litter (0.010–0.200 mm) was more abundant than the rest of micro- and meso-litter (Fig. 6). SIMPER analysis confirmed that "filaments" (synthetic, semisynthetic or natural fibres) between 0.010–0.200 mm was the item that most contributed to characterize sites with more than 52% of

**Table 1** Summary of analyses of variance (PERMANOVA) for total composition, diversity and abundance of macro- and micro−/meso-litter accumulations in the different sites and sandy beaches of Madeira Archipelago, respectively. Significant *p* values are indicated in italics

| Source | *df* | Composition | | Diversity | | Abundance | |
|---|---|---|---|---|---|---|---|
| | | Pseudo-*F* | *p* (perm) | Pseudo-*F* | *p* (perm) | Pseudo-*F* | *p* (perm) |
| Macro-litter | | | | | | | |
| Si | 3 | 2.25 | *0.013* | 2.25 | *0.0127* | 4.15 | *0.0147* |
| He | 3 | 8.27 | *0.000* | 8.27 | *0.0001* | 23.19 | *0.0001* |
| He × Si | 9 | 0.72 | 0.899 | 0.72 | 0.8986 | 1.33 | 0.2563 |
| Residual | 32 | | | | | | |
| Micro-/meso-litter | | | | | | | |
| Be | 3 | 2.65 | *0.000* | 8.13 | *0.0004* | 3.28 | 0.0678 |
| Residual | 10 | | | | | | |

*Si* site, *He* height, *Be* beach

contribution across all study sites. Specifically, blue filaments registered the highest contribution in all sites (more than 24%), except in P where this item was only the third contributor with 11.92% (Fig. 9).

With regard to colour classification, the fraction of micro-litter lower than 0.200 mm was the size that presented larger diversity of colours, mostly composed by filaments (Fig. 9). In this fraction, red and pink items were dominant. However, these colours were not found in the larger size fractions (Fig. 9). Generally, there was a predominance of cold colours (i.e. white, black, blue and grey) in micro- and meso-litter over warm colours (Fig. 10).

## 4 Discussion

This study represents the first contribution for coastal marine litter characterization in the Madeira archipelago and confirms that this global threat is also affecting this

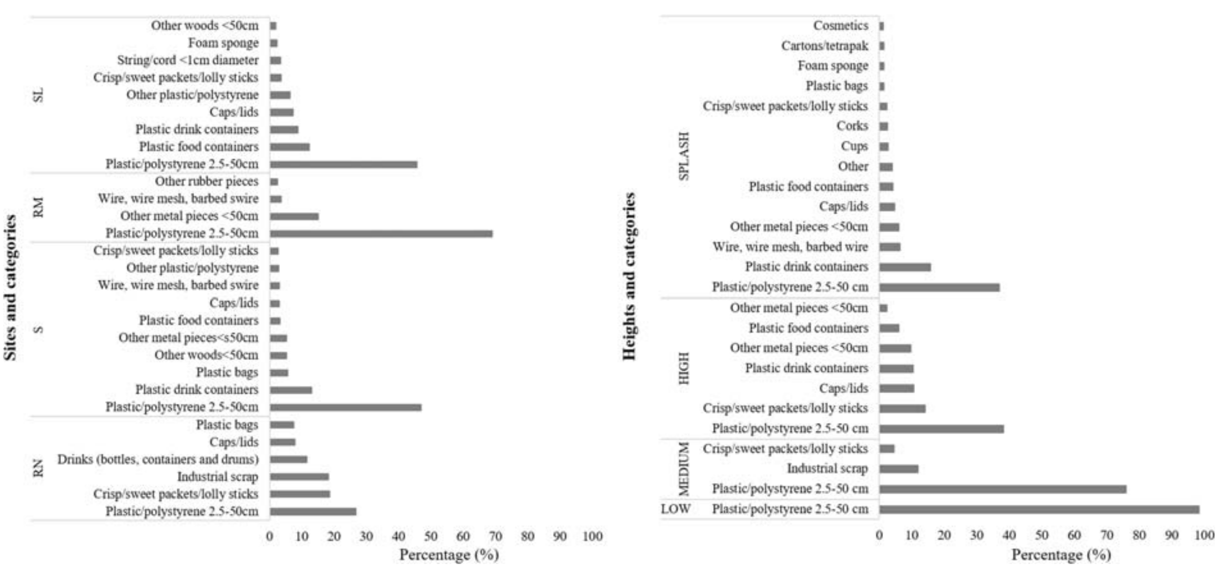


**Fig. 3** Results from similarities and macro-litter contributions (SIMPER) of macro-litter accumulations from the different sites and heights in the shore. RN = Rocha do Navio, S = Seixal, RM = Reis Magos and SL = São Lourenço

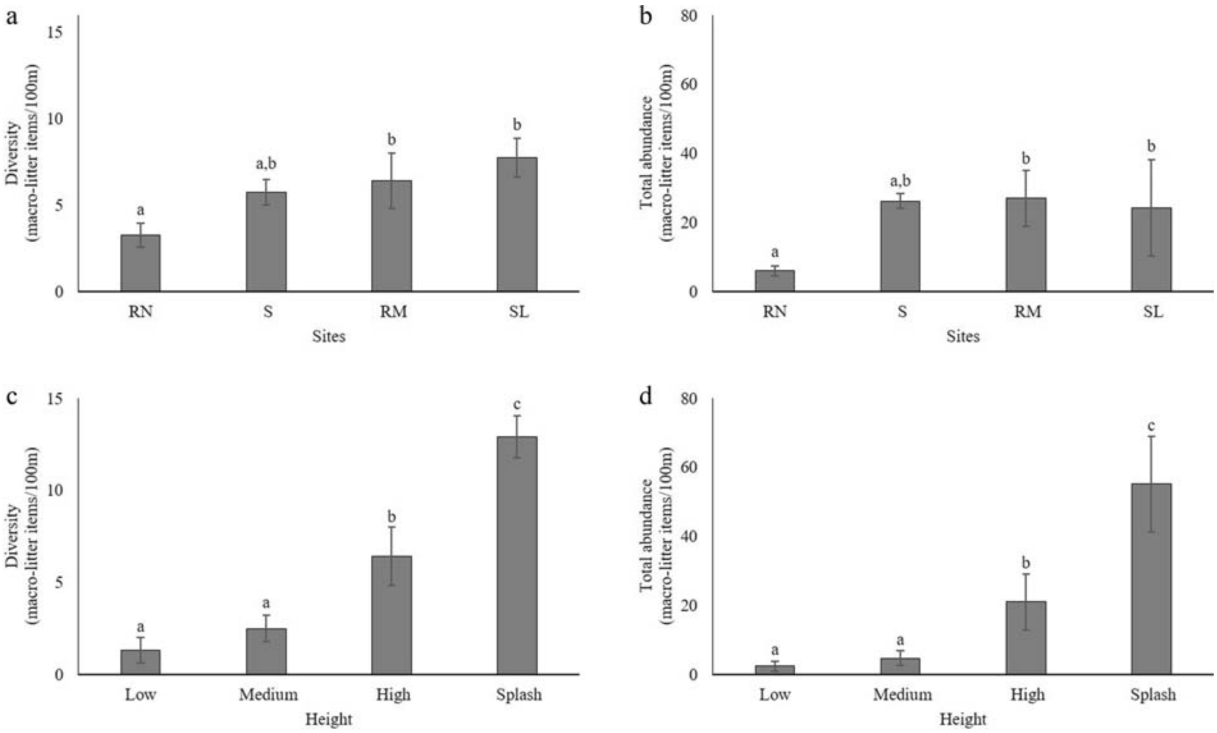


**Fig. 4** Mean (±SE) diversity and abundance of macro-litter for all study sites (**a**, **b**) and tidal heights (**c**, **d**) (n=3). RN = Rocha do Navio, S = Seixal, RM = Reis Magos, SL = São Lourenço. Significances of a posteriori pairwise tests between study sites and heights are indicated with different letters ($p < 0.05$)

region. Like many regions around the world, the archipelago is currently exposed to the influx and accumulation of macro-, meso- and micro-litter, and plastic was the principal component (Bimali Koongolla et al. 2018; Gutow et al. 2018; Rios et al. 2007; Syakti et al. 2017). The most common category of macro-litter found in our samples was plastic-polystyrene, with plastic bags, drink bottles, crisp/sweet packets/lolly sticks and plastics < 50 cm present in all sites. At the north coast of Madeira, RN revealed less macro-litter items than in all other sampling sites. This sampling site has limited accessibility and is located inside a Marine Protected Area (Decreto Legislativo Regional n.º11/97/M. Série A. Nº174 - 30-7-1997 1997) and therefore has lower pressure resulting from human activities. A similar rationale could be applied to SL, also located in a protected terrestrial area. However, the abundance of marine litter detected in SL was not significantly different from the abundances found in the other non-protected study sites. The sampling area in SL was in fact located closed to the nesting area for a few species of seabirds like *Larus michahellis*, *Hydrobates castro*, *Calonectris borealis* and *Bulweria bulwerii* (Instituto das Florestas e Conservação da Natureza IP-RAM 2009). The area is also commonly visited by the endangered monk seal (*Monachus monachus*), even more after the effort done by LIFE Madeira Monk Seal project (Secretaria Regional do Ambiente e Recursos Naturais and CBD-Habitat 2014). However, at a local scale, the easy accessibility and the less restricted human activities in comparison with the fully Marine Protected Area of Rocha do Navio could have allowed a higher concentration of litter (Resolução n.º1294/2009 2009). The different exposure of the selected study sites (RN in the North and SL in the South) and the ocean currents (Barton 2001; Caldeira et al. 2002) might be also contributing to influence the observed patterns of accumulations between sites (Chambault et al. 2018; Sala et al. 2016).

The four study sites used for macro-litter sampling revealed the same tidal height tendency, with more litter items found at both high and splash zones. In addition, we observed that the North-orientated sites, S and RN, displayed this pattern in a more pronounced fashion, with a higher difference in macro-litter items found between lower and high tidal levels.

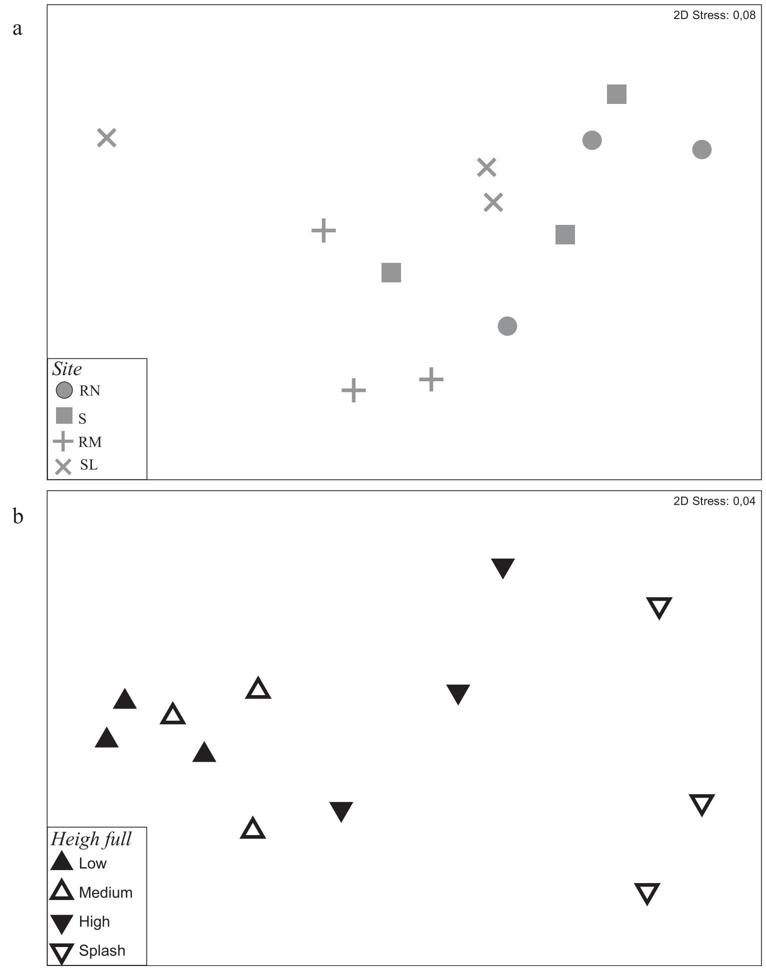


**Fig. 5** Nonmetric multidimensional scaling produced with values from number of macro-litter accumulated **a** in the different locations sampled along the Madeira Archipelago and **b** across the different heights in the shore. RN = Rocha do Navio, S = Seixal, RM = Reis Magos and SL = São Lourenço

Similarly, micro-litter was also present in all sampled study sites, confirming their global widespread and ubiquitous behaviour (Andrady 2011; Barnes et al. 2009). When compared with the other categories or items, the number of filaments found was very high and was present in all sites. However, the sampled sites were located in areas where the wastewater treatments are secondary (which involve biologic processes to eliminate the organic matter from the effluent) or tertiary (the last process of wastewater treatment, which remove from the effluent pollutants present after the other treatments as particles difficult to decant or pathogenic organisms), except in Funchal, which is preliminary treatment (removal of large items that may damage the treatment process) (Correia Machado 2016; Habib et al. 2020; Mason et al. 2016; Murphy et al. 2016). These items were probably originated from domestic activities (e. g. wash clothes) as wastewater treatments do not eliminate completely these items of the effluent (Mason et al. 2016; Murphy et al. 2016). The sampling sites PC and S2, both located in the North coast of Madeira, were characterized to have, in addition to filaments, other micro-litter items in the smallest fraction (< 0.200 mm). In contrast, sites located in the south coast of Madeira showed a different scenario with site P characterized by the presence of filaments smaller than 0.200 mm and site F for having also litter in all fractions from 0.010 to 25 mm. Formosa site is located in Funchal, the island's capital, and therefore exposed to more human pressure. However, the low-dense populated site of PC showed a similar scenario as site F, characterized by micro-litter larger than 1 mm and also meso-litter. Also, in the neighbour island Porto Santo, filaments were very predominant and also characterized by some pellets but always smaller than 0.200 mm. Therefore, other sources not only related with the proximity to high dense urban areas, i.e. ocean and/or coastal currents, seem to be promoting the transport and accumulation of really small plastic items in sites with a priori lower anthropogenic pressure.

In what refers to colour identity, all study sites followed the same pattern. The diversity of colours decreased with increasing the size of items, and filaments is the more diverse item in terms of colour identity. Although FTIR-Spectrometer analyses was not carried out in our study to confirm the synthetic composition of items to better understand the origin of them, with regard to the colour results, it is possibly to affirm that micro-litter smaller than 0.200 mm, specifically filaments, comes from different origins since it is assumed that the diversity of colours is directly related with the origin (Gallagher et al. 2016). In this study, more than 80% of the micro and meso-litter items identified in Madeira displayed white, black, grey and blue colours (cold colours). In contrast, only a small fraction of filaments (smaller than 0.200 mm) showed warm colours. Probably this fact is explained by the idea suggested from previous studies that predominant colours in microplastics are majority white, blue and green due to photo degradation of the incorporated pigments (Matsuguma et al. 2017; Syakti et al. 2017). This degradation could be associated with the environmental exposure suffered during their oceanic transport, supporting again the idea that site accumulations, particularly of these small fractions, are more related to their ocean connectivity to distant sources, via coastal or ocean currents, than their proximity to urban areas (Yu et al. 2018).

In addition, we have not enough information to affirm that the north coast of Madeira is a marine litter deposit area like what was suggested to happen in the neighbour Canary Islands with beaches exposed to open ocean (Baztan et al. 2014; Herrera et al. 2018a). However, a similar phenomenon could be happening in Madeira because both island systems are under similar oceanic conditions, but detailed research is needed.

Furthermore, similarly to what is implemented in several community ecology studies, we considered litter categories as proxies for species and have therefore conducted multivariate analyses. We believe this approach is novel; to the best of our knowledge, it was never applied in marine litter characterization studies and has the potential to improve the robustness of litter accumulation patterns, visualizations and interpretations.

This study confirms that the coastline of the Madeira Archipelago, like other global regions, is currently affected by the marine litter problem. We have identified the presence of marine litter items from different size categories, being filaments the most abundant item of micro-litter and plastic as the most representative of

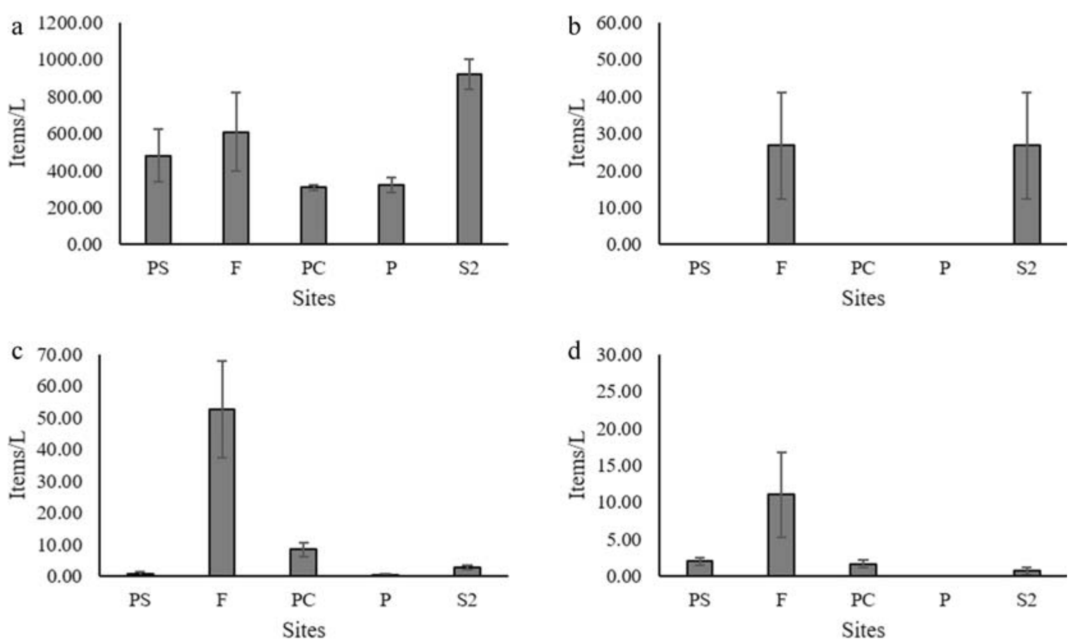


**Fig. 6** Average (±SE) of micro- and meso-litter items/L abundance in sediment from the study sites sampled in the Madeira Archipelago (*n* = 3). Items sizes: **a** 0.010–0.200 mm; **b** 0.200–1 mm; **c** 1–5 mm; **d** 5–25 mm. PS = Porto Santo, F = Praia Formosa, PC = Porto da Cruz, P = Prainha and S2 = Seixal2.

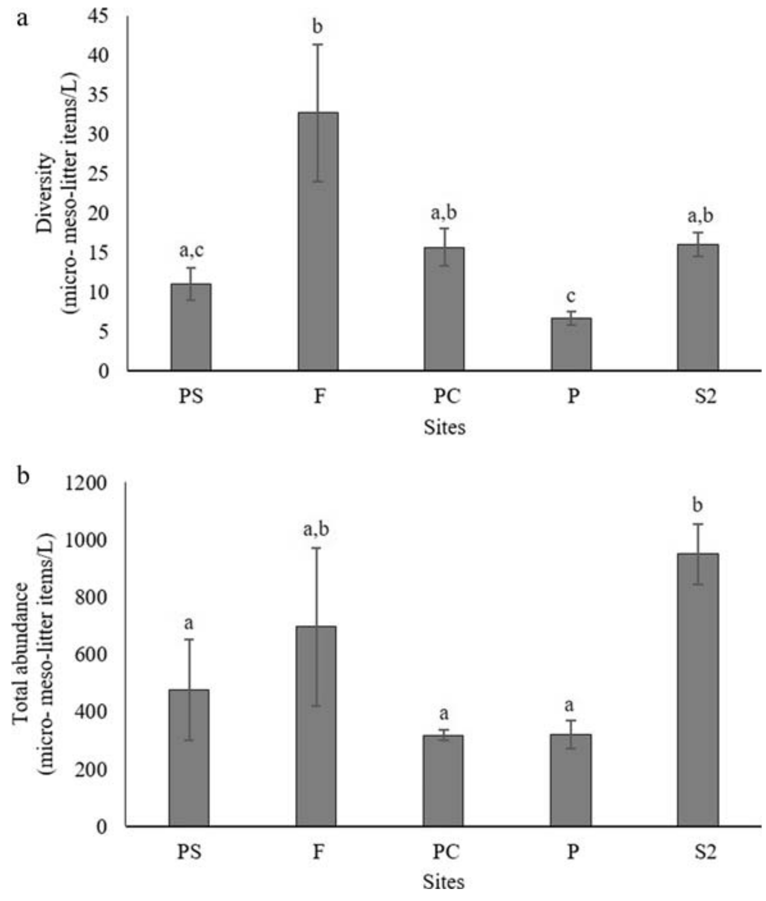


**Fig. 7** Mean (±SE) micro- and meso-litter **a** diversity and **b** abundance for each study site sampled in Madeira Archipelago (n = 3). PS = Porto Santo, F = Praia Formosa, PC = Porto da Cruz, P = Prainha and S2 = Seixal2. Significances of a posteriori pairwise tests between study sites are indicated with different letters ($p < 0.05$)

macro-litter. Finally, this study establishes the first baseline for marine litter characterization, but it should be complemented with additional surveys and FTIR spectroscopy analysis in future research, particularly focusing in different study sites in both Madeira and Porto Santo Islands and should address different temporal scales.

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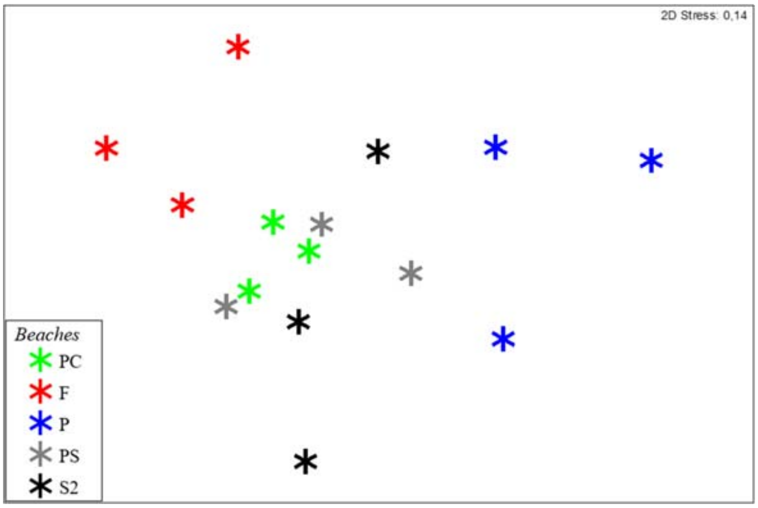


**Fig. 8** Nonmetric multidimensional scaling produced with values from number of micro-litter (items/L) in sandy sites of the Madeira Archipelago. PC = Porto da Cruz, F = Praia Formosa, P = Prainha, PS = Porto Santo and S2 = Seixal2

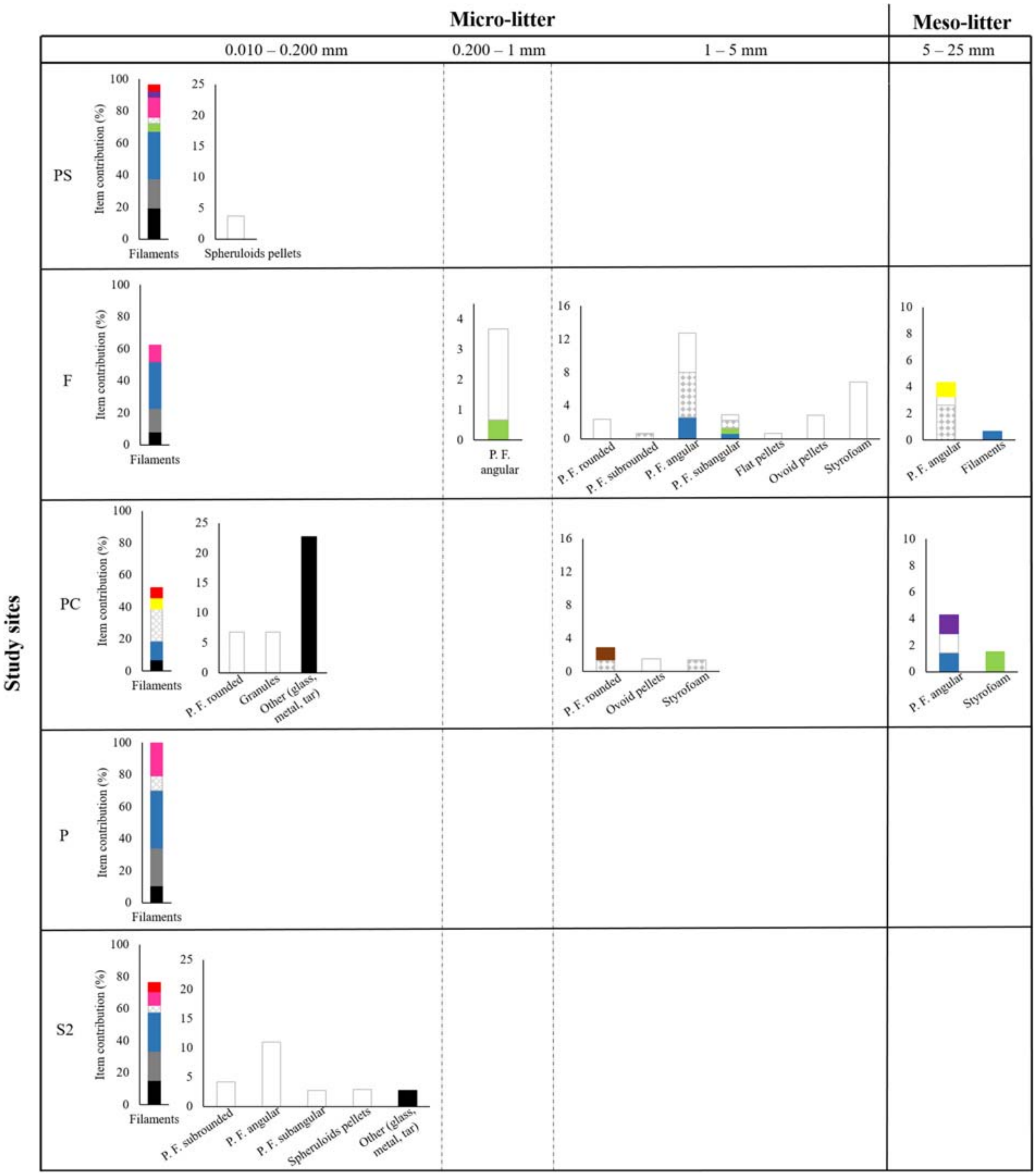


**Fig. 9** Characterization of the study sites sampled according to the items, size and colour contribution for micro- and meso-litter, PS = Porto Santo, F = Formosa, PC = Porto da Cruz, P = Prainha and S2 = Seixal2. The colours represented in the bar corresponding to the real colour of the items. ▢ Represent transparent items; ▢ Represent semi-transparent items. P. F. = plastic fragment

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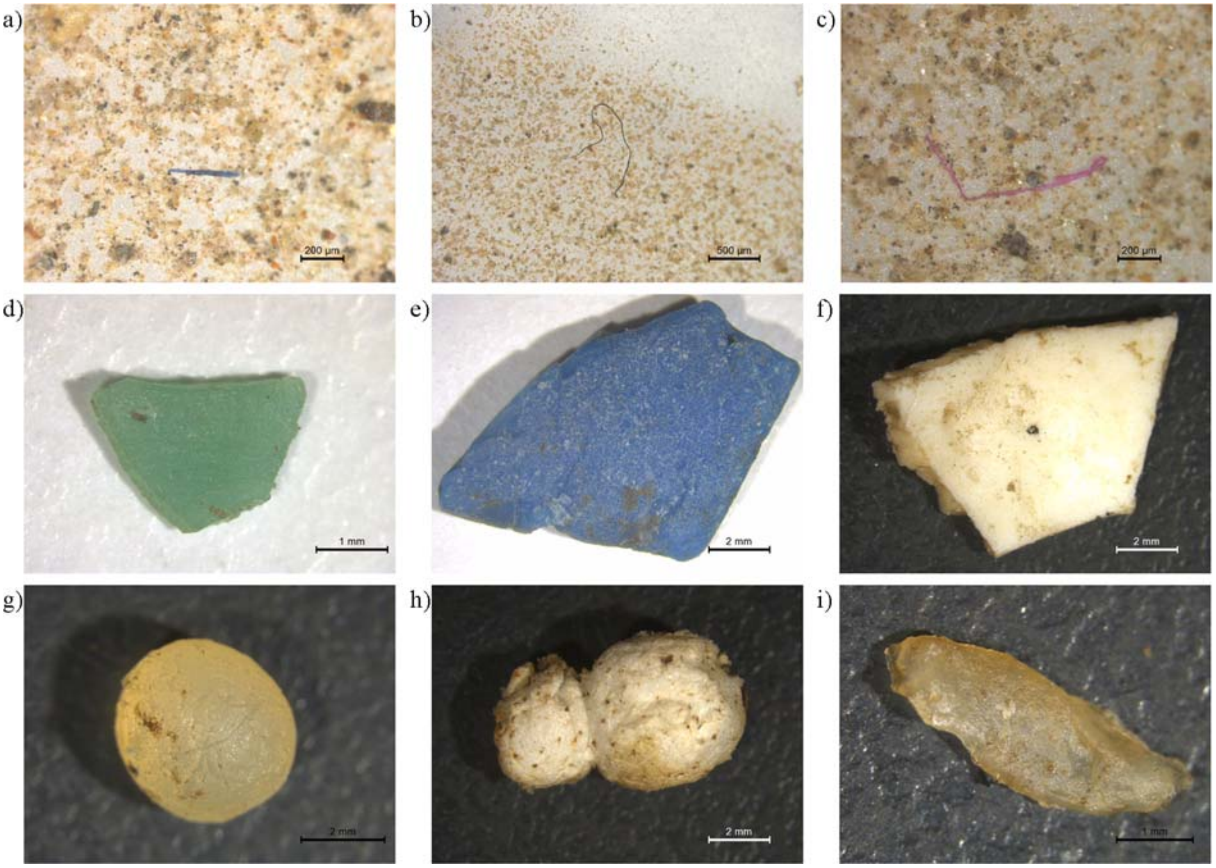


**Fig. 10** Some examples of items of mico- and meso-litter sampled. **a**, **b**, **c** and **d** filaments and fragment from Praia Formosa; **e** and **f** fragments from Porto da Cruz and Porto Santo; **g** pellet from Porto da Cruz; **h** styrofoam from Porto Santo; **i** fragment from Seixal2

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### Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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