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Searching for hotspots of neustonic microplastics in the Canary Islands

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ABSTRACT

In this study, we investigated the concentration, distribution, and characteristics of neustonic MPs in the Canary Islands, with a particular focus on the island leeward zones, where a high accumulation of floating marine microplastics is expected. Samples were collected with a manta net at 15 different sites from Alegranza to La Gomera during the IMPLAMAC expedition. The microplastic concentration in surface waters ranged from 0.27 MPs/m^3 in Alegranza to 136.7 MPs/m^3 in the south of Gran Canaria. The highest concentration of MPs found was due to the presence of a sea-surface slick, also called "marine litter windrow", formed in the south of Gran Canaria. The most abundant zooplankton group in the neuston was copepods, except at the marine litter windrow where fish larvae and eggs predominated. This indicates that coastal areas where marine litter windrows are formed have a high risk of MP ingestion and potential adverse effects on biota.

1. Introduction

Plastic production has continually increased since the 1950's, reaching a maximum of 390.7 million tonnes in 2021 (Plastics Europe, 2021) despite government initiatives and public awareness campaigns to reduce the use of disposable plastic items. It is estimated that between 4 and 12 million tonnes are annually discharged into the sea (Jambeck et al., 2015) and, if we continue with the same rate of production and dumping, 90 million tonnes per year could enter the ocean by 2030 (Borelle et al., 2020). The accumulation of plastic debris in the ocean and its potential effects on marine ecosystems are major environmental concerns. Plastics in sea surface waters are only the tip of the iceberg. They represent only 15 % of the total amount of plastics discharged in marine systems, as 15 % are suspended in the water column, and the remaining 70 % is accumulated on the seafloor (Eriksen et al., 2014). Among plastic debris, microplastics (MPs) are now ubiquitous contaminants in aquatic environments. There is currently no consensus on the classification of plastics by size. The US National Oceanographic and Atmospheric Administration (NOAA) proposed that microplastics are any plastic particles smaller than 5 mm (Arthur et al., 2009), whereas more recently Frias and Nash (2019) have proposed to consider microplastics those plastic particles between 1 μm- 5 mm, defining nanoplastics as those smaller than 1 um in size; and Hartmann et al. (2019) recommend including in the microplastics category the size range from 1 to <1000 μm.

The spatial distribution of plastic and microplastic debris in marine surface waters is heterogeneous and linked to oceanographic processes at different scales. For instance, large-scale (>200 km) oceanographic processes like ocean circulation by Ekman currents cause the accumulation of plastics in the convergence zones. Other processes at the meso- (10–200 km) and submeso- (<10 km) scales such as eddies, topographically controlled fronts, internal waves, and minor surface convergences can also cause the aggregation of floating plastic debris (Suaria et al., 2021). These accumulations of positively buoyant plastics and other floating particles, typically narrow meandering lines, are commonly called "sea surface slicks" (Gove et al., 2019). Sea surface slicks can accumulate 126 times more plastic than the surrounding waters, but at the same time act as important nurseries for fish larvae (Gove et al., 2019). These authors found plastic pieces in 8.6 % of fish larvae inside the accumulation lines, with an occurrence 2.3 times higher than in fish larvae samples outside these specific areas. Cózar et al. (2021) call surface slicks "marine litter windrows" defining them as any aggregation of floating litter in the mesoscale range (<10 km horizontally), regardless of the force that produces them, such as wind or tides. Windrows can be identified at the sea surface as lines of foam and debris generally aligned with the wind that are formed by convergence zones between pairs of wind-wave induced, counter-rotating, wind-parallel helical vortices called Langmuir circulation (Van Sebille

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et al., 2020). Marine litter windrows are hotspots for the accumulation of marine debris and areas of interaction with marine organisms. For these structures to be formed, a combination of two factors is necessary, the first is the presence of a convergence zone at the ocean surface and the second is a high concentration of marine litter (Cózar et al., 2021).

The Canary Islands (27° 37′ - 29° 25′ N and 13° 20′ - 18° 10′ W) are located in the North Atlantic subtropical gyre and influenced by the Canary Current, which is fed by a branch of the Azores Current. The Canary Current transports high concentrations of plastics that ultimately reach the Canarias archipelago (Eriksen et al., 2010). As the Canary current flows, it encounters the islands, which act as a natural barrier to the passage of oceanic and atmospheric flows. These conditions generate mesoscale structures such as cyclonic and anticyclonic eddies, and warm water wakes in the lee of the islands with higher altitudes such as Gran Canaria (Arístegui et al., 1994; Barton et al., 1998; Sangrà et al., 2009). The island effect generates two eddies, one to the southwest and the other to the southeast of the Gran Canaria Island where they give rise to a divergent (upwelling) and convergent (subsidence) fronts, respectively (Arístegui et al., 1994; Hernández-León et al., 2007). Convergence processes will induce the formation of marine litter windrows in regions with a particularly high concentration of debris at the sea surface, which a priori includes the macroscale accumulation zone of subtropical gyres (Law et al., 2010) or waters close to debris sources such as rivers and cities (Pedrotti et al., 2016). The presence of marine litter at the surface and the occurrence of marine litter windrows are of particular concern for filter-feeding organisms (de Sá et al., 2018; Thompson et al., 2009).

This study aims aim to determine the abundance, distribution, and characteristics of neustonic microplastics (> 200 μm) in the Canary Islands including marine debris accumulation zones like marine litter windrows. Additionally, we estimated the mass ratio between zooplankton and microplastics in the collected neuston samples.

2. Material and methods

2.1. Sample collection

Neustonic microplastics and plankton samples were collected from Alegranza to La Gomera during the IMPLAMAC expedition from October 4 to 18, 2021. For this study, we also used 4 samples collected before the expedition: 2 samples from Alegranza, and 2 from El Hierro, following the same metodhology (Table 1). Hence, a total of 18 samples from 15 sites in the Canary Islands were considered in this study (Fig. 1, Table 1).

Samples were collected with a manta net of a 25 × 60 cm mouth dimension and a mesh pore size of 200 μm. The trawl was dragged at a speed of 3 nautical knots for 20 min, for approximately 1 nautical mile. The volume of water filtered during the transects was calculated using a General Oceanic flowmeter (203RC). Samples were preserved in 70 % ethanol until further analysis in the laboratory.

The IMPLAMAC expedition was conducted aboard the sailing vessel “Windfall”, the objective was to sample in potential accumulation areas. We were searching for mesoscale structures, eddies that are formed south of Gran Canaria, and during the navigation we “accidentally” found the marine litter windrow. When we found the windrow we sampled for only half a nautical mile (due to clogging of the sampling net) following the litter stream line. The windrow was seen as a continuous line of foam, leaves and floating debris >1 km long.

2.2. Sample processing

The whole sample extraction procedure was performed in a sterile environment to avoid contamination of the samples by synthetic fibres. For this purpose, the working area was cleaned with alcohol, cotton lab coats were used, and all utensils were adequately sterilised and cleaned with double distilled water. A petri dish with a 25 μm mesh was placed near the stereomicroscope during sample inspection as a contamination control.

First, each sample was separated into three sub-samples according to size using a sieve column (size range > 1000 μm; size range 500–1000 μm; size range 200–500 μm). Each sub-sample was stored in a 250 mL bottle and preserved in 70 % ethanol.

For each 250 mL sub-sample, three aliquots of 2 mL were analysed to identify and quantify zooplankton. To facilitate the interpretation of the results, the organisms were grouped and classified into the following taxonomic groups: amphipods, copepods, chaetognaths, decapod larvae, ichthyoplankton (egg and fish larvae), cladocerans, ostracods, gastropod larvae, bivalve larvae and jellies (includes cnidarians, salps, and ctenophores). The “other arthropods” category includes barnacle larvae, insects (*Halobates*), mysids, euphausiaceans, and stomatopods. The “others” category is composed of the following: annelids, appendicularians, and foraminifers. These two last categories are comprised of organisms with a frequency of <0.1 % in the whole sub-sample.

After identification and quantification of the zooplankton, the aliquots were returned to the corresponding sub-sample. The whole sub-samples were filtered, and their wet weight was determined with a high precision balance (Precisa LT120A). Then, the sub-samples were dried in an oven at 60 °C for at least 24 h. After drying, the samples were

Table 1
Abundance of microplastics in items/m^3 and items/km^2; and ratio microplastics/zooplankton in abundance (microplastic items/zooplanktonic individuals) and dry weight (DW) for each sampling location. *Only for size fraction (1000–5000 μm).

Island	Location	Sample	Microplastics (>200 μm)		Ratio MPs/Zoo	
			Items/m^3	Items/km^2	Items	DW (mg)*
Lanzarote	Arrecife	ST1	0.27	33,907	5.4×10^{-4}	–
		ST1.2	0.39	48,525	5.8×10^{-4}	–
	Playa Blanca	ST2	0.53	66,195	10.2×10^{-4}	0.05
Fuerteventura	Caleta de Fuste	ST3	1.21	151,244	20.6×10^{-4}	0.14
	Gran Tarajal	ST4	1.52	190,580	2.4×10^{-4}	0.02
Gran Canaria	Las Canteras	ST5	0.70	86,947	3.1×10^{-4}	0.30
	Taliarte	ST6	0.67	83,760	12.3×10^{-4}	–
	Maspalomas	ST7	4.94	617,391	10.6×10^{-4}	–
	Pasito Blanco	ST8	136.7	17,087,561	23.6×10^{-4}	1.50
		ST8.2	21.66	2,706,953	16.3×10^{-4}	0.34
Tenerife	Los Cristianos	ST9	8.35	1,043,727	61.8×10^{-4}	0.12
La Gomera	Playa de Santiago	ST10	6.54	817,847	20.2×10^{-4}	–
	Punta de la Fuente	ST11	4.39	548,166	13.4×10^{-4}	0.35
Tenerife	El Caletón	ST12	1.65	206,755	21.5×10^{-4}	–
El Hierro	El Hierro	ST14	0.3	37,797	5.33×10^{-4}	0.12
		ST14.2	0.26	32,397	5.1×10^{-4}	0.20
Alegranza	Alegranza	ST15	0.34	42,406	23.8×10^{-4}	0.07
		ST15.2	0.27	33,563	9.7×10^{-4}	0.13

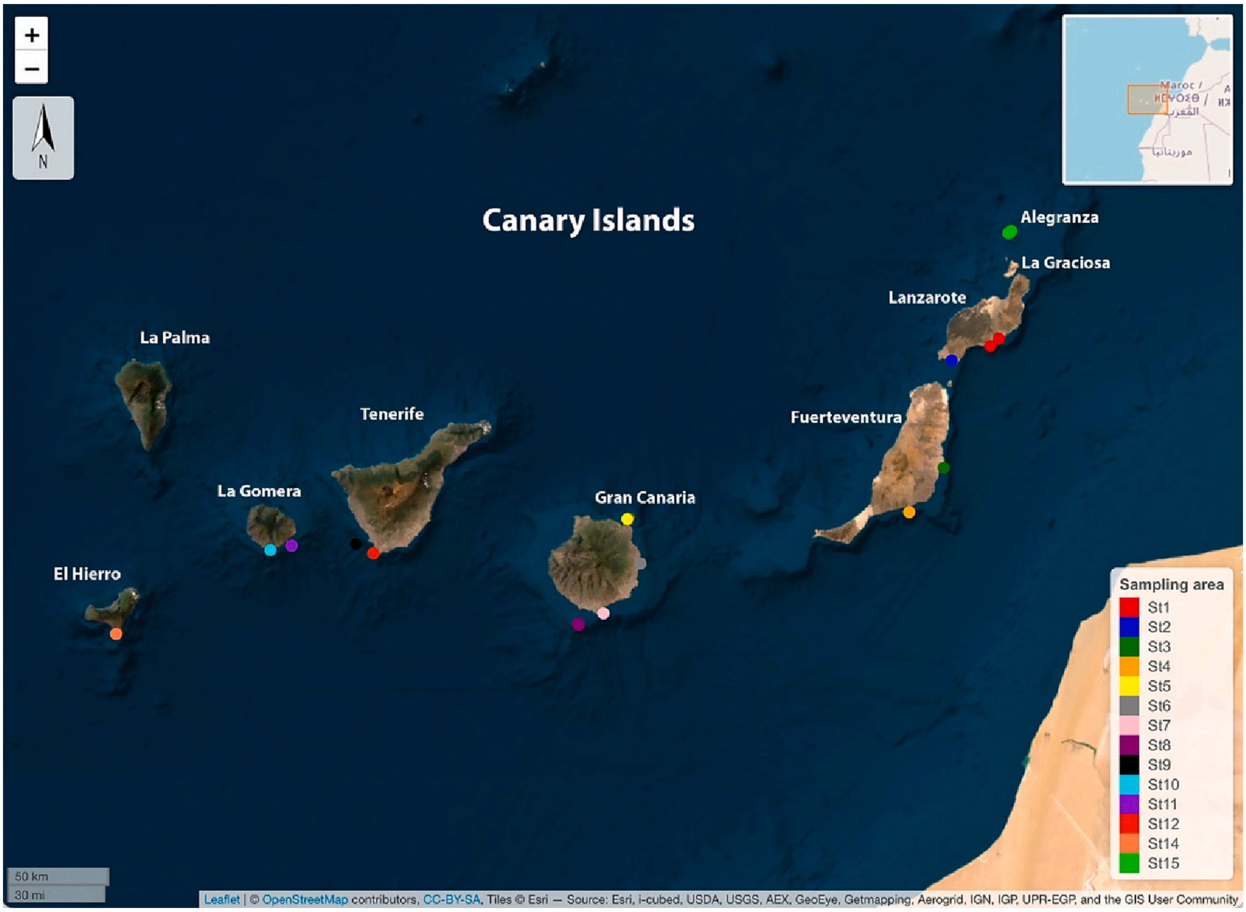

Fig. 1. Study area. The dots with different colours represent the sampling sites.

weighed again to obtain the dry weight. Potassium Hydroxide (KOH) (10 %) was added to the samples in an oven at 60 °C for at least 24 h to digest organic materials and facilitate the identification of the microplastics. The samples were then filtered and "sealed" in a sterilised Petri dish to avoid contamination by fibres.

All samples were identified and visually counted with a stereomicroscope (Leica S9i) with an integrated CMOS camera. The suspected plastic items and tar was classified according to shape/typology; fibres, fragments, films, fishing lines (lines), industrial pellets (pellets), foams and tar. Fibres finally were not accounted because although measures were taken to avoid contamination in the laboratory, it is impossible to guarantee that atmospheric deposition did not occur during sampling. Tar although it is not a microplastic, it can be considered a micro-debris of anthropogenic origin, for convenience we have included this category together with microplastics.

The items were also sorted by colour, specifically in 9 colour ranges with their different shades: transparent, white, clear; yellow, yellowing; orange, brown; red, pink; green; blue; purple; grey, silver; black, dark.

Additionally, the suspected plastic items found in each sample were separated for polymer type determination by Fourier transform infrared spectrometer (FTIR) using a Perkin Elmer Spectrum Two FTIR instrument, equipped with a diamond ATR unit and a MIR TGS detector. At least 30 % of the particles larger than 1 mm were analysed; in the case that there were <10 particles in the entire sample, all items were analysed.

3. Results

3.1. Abundance and distribution of microplastics (200–5000 μm)

All the analysed samples contained microplastics (Fig. 2, Table 1). A total of 3825 items were counted, excluding fibres. The concentrations (items/m^3) varied notably among stations, from 0.27 to 136 items/m^3 (Fig. 2, Table 1). The lowest MPs concentration was found at the Arrecife (ST1) and Alegranza Island (ST15.2) and the highest in Pasito Blanco, Gran Canaria (Fig. 2, Table 1). At several stations, the concentration of microplastics was <1 item/m^3; higher concentrations were found in the leeward zone of the islands with high altitude (ST9 southwest of Tenerife) with 8 items/m^3 and south of La Gomera with 6 items/m^3 (Fig. 2, Table 1).

3.2. Characteristics of microplastics

Shape/type: As shown in Fig. 2, in the majority of the stations sampled, the most abundant types of MPs were fragments (Fig. 2). To have a general overview, we quantified the composition of plastic types by combining all the samples (Fig. 4a). Fragments were the most abundant type with 77.2 % of the total, followed by tar with 15.7 % and films with 3.9 %.

Regarding MPs size, in the total items, the percentage of each size range was 33.6 % (>1000 μm); 49.7 % (500–1000 μm); and 16.7 % (200–500 μm) (Fig. 4c). As shown in Fig. 3, in each sampling location the predominant fraction differed. The 500–1000 μm fraction was the most abundant in ST4, ST5, ST7, ST8, ST9, ST11, ST12 and ST14, while ST1, ST1.2, ST3, ST6, ST10, and ST15 contained more particles between 200 and 500 μm; only in ST8.2, the most abundant fraction was >1000

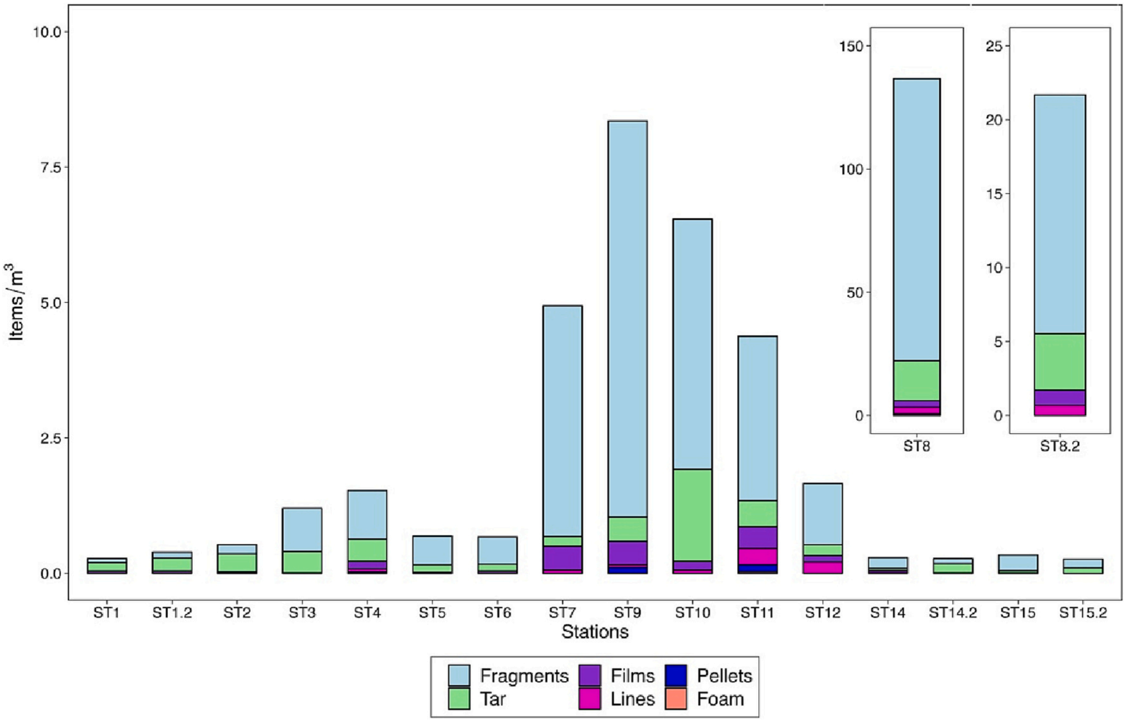

Fig. 2. The abundance of microplastics (items/m^3) and their shape/type composition in the sites sampled in the Canary Island. Stations ST8 and ST8.2 have been plotted separately to correctly visualize the scale since the values exceeded the majority of the samples by one order of magnitude.

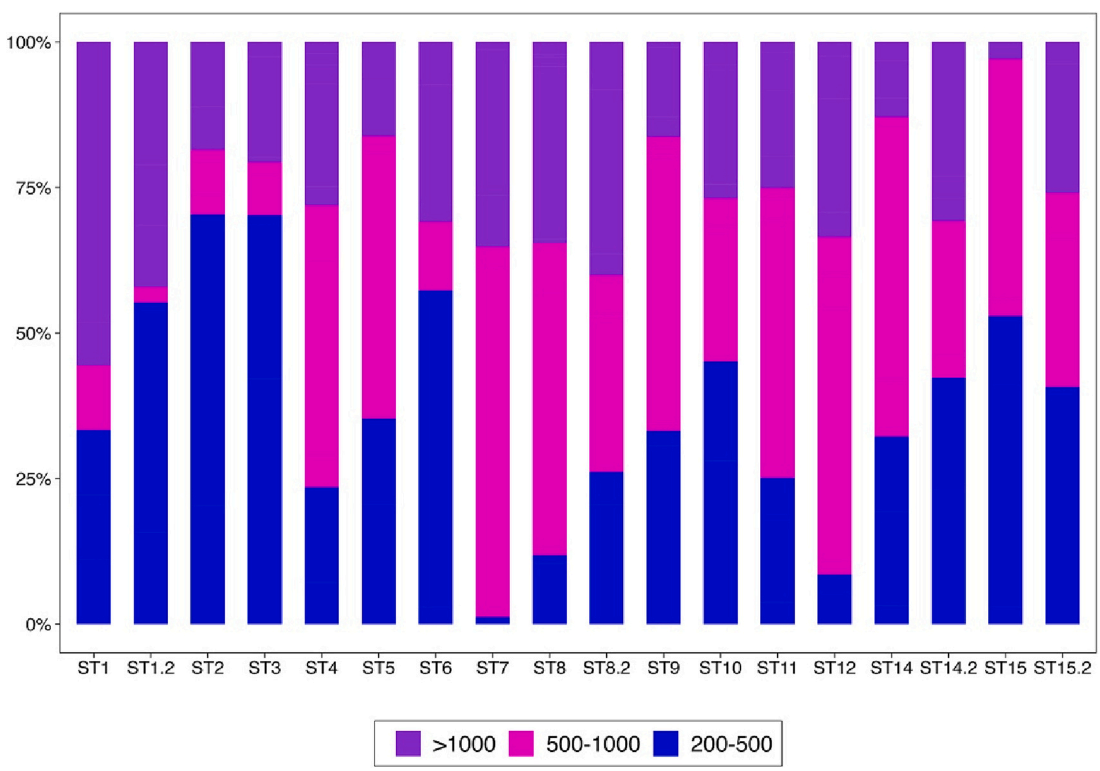

Fig. 3. Size fraction composition (%) of neustonic microplastics in the different sampled sites in the Canary Islands (size ranges >1000 μm; 500–1000 μm; 200–500 μm).

μm.

The main colour recorded for the isolated plastics was white/transparent (52.6 %), followed by black particles (20.1 %), blue (8.2 %) and green (6.2 %), as shown in Fig. 4b. The remaining categories accounted for <5 % each, with purple containing the lowest abundance.

The most frequently detected polymer types were high-density polyethylene (HDPE) and polypropylene (PP), accounting for 64.7 % and 27 % of the identified MPs. Polystyrene (PS) accounted 0.2 %, and

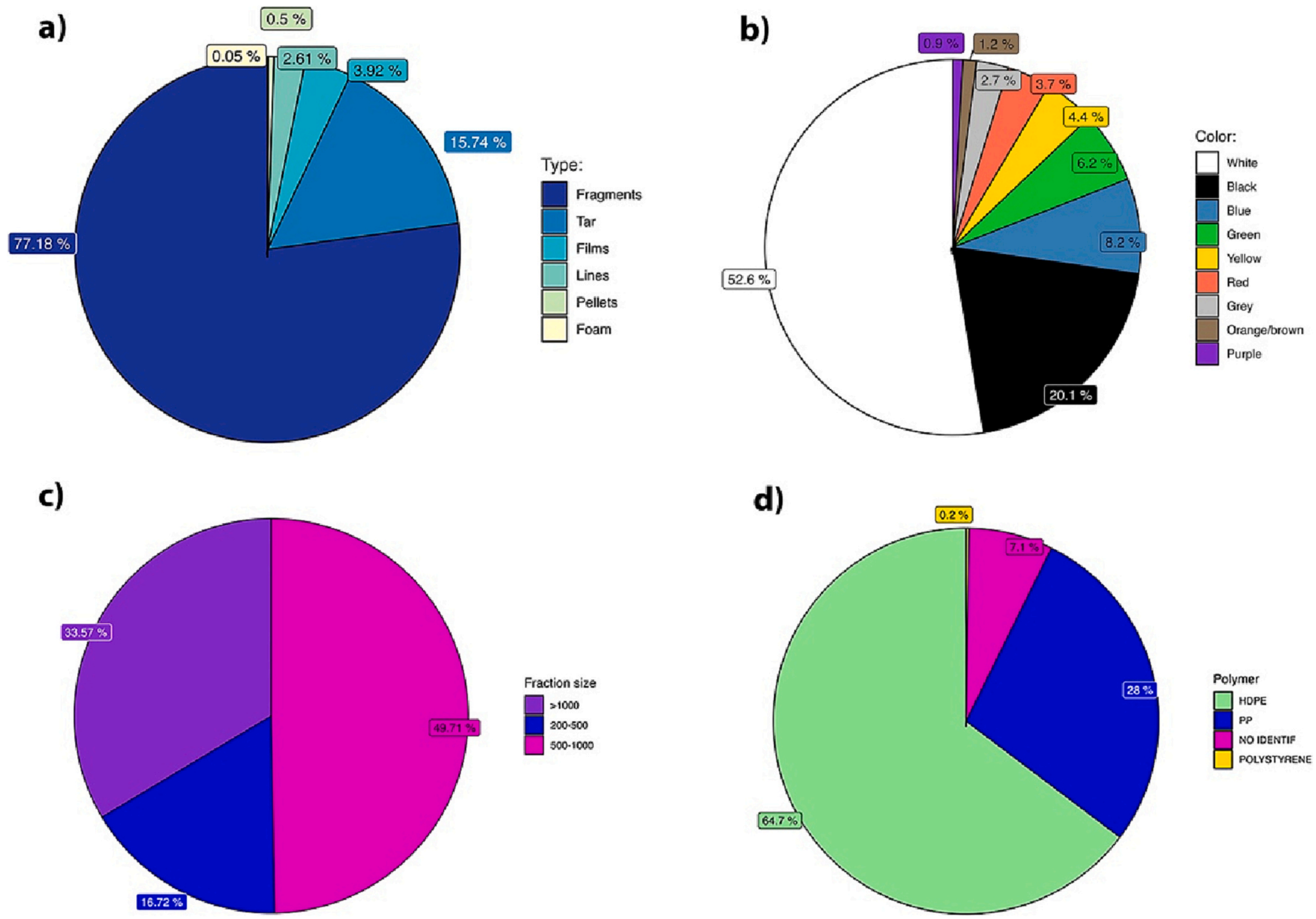

Fig. 4. Percentages in total items sampled (3825 items) excluding fibres. a) Shape/Type. b) Colours. c) Size fraction (size ranges >1000 μm; 500–1000 μm; 200–500 μm). d) Polymer composition determined by FTIR in 30 % of total items >1 mm at each sample. Polyethylene, high density (HDPE), Polypropylene (PP), Polystyrene (PS), and no identified polymer (NO IDENTIF).

the remaining 7.1 % could not be identified by FTIR (Fig. 4d).

3.3. Zooplankton abundance and composition; ratio microplastics/zooplankton

The maximum abundance of zooplankton was found at ST8 (Pasito Blanco, Gran Canaria) with 58,020 ind/m^3 followed by ST8.2 (Pasito Blanco, Gran Canaria) with 13,268 ind/m^3. The lowest zooplankton abundance was found at Alegranza with 142 ind/m^3 (Fig. 5).

In the majority of the samples, the most abundant group of zooplanktonic organisms was copepods, however, in some stations, especially where microplastic accumulations were found (ST8 and ST8.2), the predominant group was the fish larvae and eggs (Fig. 5).

The microplastics/zooplankton dry weight (DW) ratio was only estimated for some of the samples in the size range 1000–5000 μm, with sufficient plastic to be weighed on a precision scale (Min weight 10 mg) (Table 1). The maximum value obtained in MPs/zooplankton DW ratio of 1.5 was in ST8, and the minimum value of 0.02 was found in ST4. Regarding the abundance ratio between items MPs/zooplanktonic individuals, values ranged from 2.6×10^{-4} in ST4 and 67.8×10^{-4} in ST9 (Table 1).

4. Discussion

Microplastics (200–5000 μm) were found in all stations and their mean concentration in the Canary Islands was 10.6 ± 31.9 items/m^3, however, the high variability found between sampling sites indicates that it is more appropriate to use the median value for comparative purposes (median 0.95 items/m^3). Most studies report the mean and not the median values, which made comparison difficult. The mean value found here was 1–2 orders of magnitude higher than the mean concentrations reported for surface waters in the North Atlantic, and other seas/marine regions (Beiras and Schönemann, 2020), although the median values found are similar to those of the cited studies. Concentrations of MPs higher than 1 MP/m^3 have also been found in the Mediterranean (Beiras and Schönemann, 2020), the Bay of Brest, France (Frère et al., 2017), the Baltic Sea (Gewert et al., 2017), Korea or Hong Kong (Kang et al., 2015; Cheung et al., 2018). However, it should be noted that samplings were done with different sampling nets, which could cause the results to be significantly different from those obtained in the present study.

Herrera et al. (2020) conducted the first quantification of neustonic MPs in the Macaronesia region with a manta net. They found high variability in the MPs concentration, with values ranging from 15,283 items/km^2 in Los Gigantes (Tenerife) to 1,007,872 items/km^2 in Las Canteras (Gran Canaria), sixteen-fold less than the maximum found in our study in ST8 (Pasito Blanco, Gran Canaria). While Herrera et al. (2020) measured 1,007,872 items/km^2 in Las Canteras, our data show a remarkably lower concentration at the same location (86,760 items/km^2). These accumulation phenomena seem to show a strong temporal variability governed, among other factors, by oceanographic conditions and the arrival of microplastics conveyed by the Canary Current (Herrera et al., 2022, 2018).

Regarding the type of MPs found, most of them were fragments.

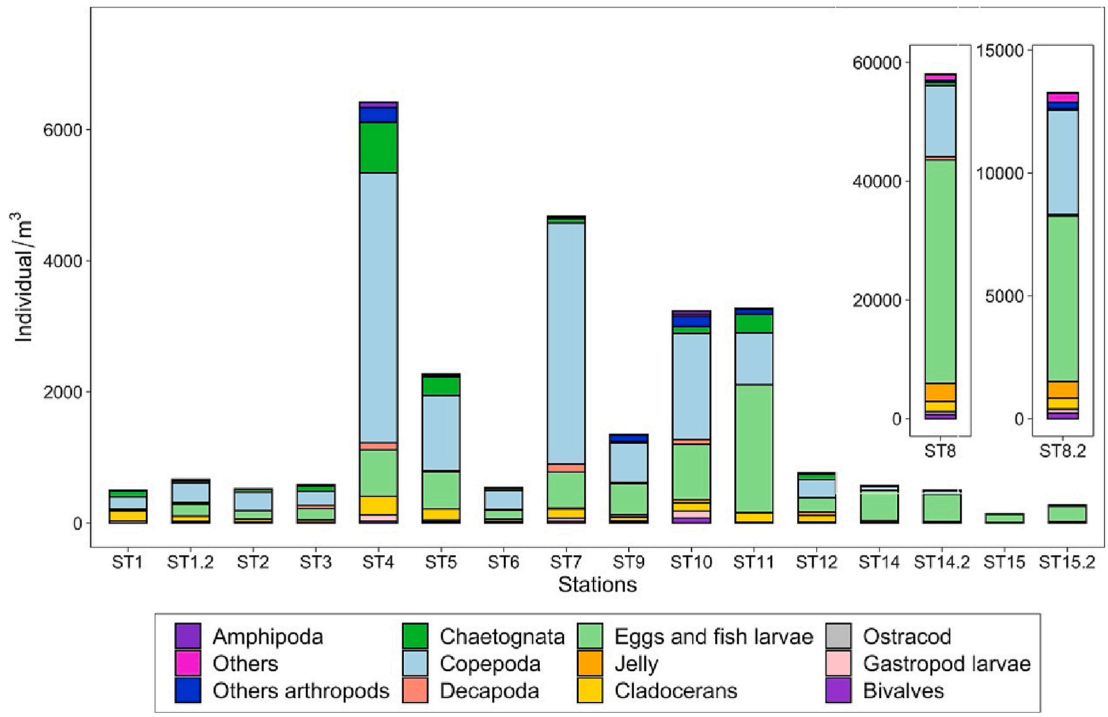

Fig. 5. Abundance of neustonic zooplankton in individuals per m^3 for each station. Stations ST8 and ST8.2 have been plotted separately to correctly visualize the scale, since the values exceeded majority of the samples by one order of magnitude.

Fragments and fibres are the main MPs types commonly found in different marine organisms in the Canary Islands such as in Atlantic chub mackerel (*Scomber colias*) (Herrera et al., 2019), jellyfish *Pelagia noctiluca* (Rapp et al., 2021) or seabirds *Oceanodroma castro* and *Larus michaellis* (Navarro et al., 2023). Probably in some areas the higher abundance of fragments increases the risk of exposure for these organisms. However, in the case of Cory's shearwater (*Calonectris borealis*), the predominant type has been fishing lines, with higher values than fragments and fibres (Navarro et al., 2023).

Another abundant type of micro-debris found was tar. This is the first time such a high tar concentration has been reported at the water surface in the archipelago. Most of the tar was found in the stations of the eastern islands (Alegranza, Lanzarote and Fuerteventura) and the stations of Pasito Blanco, affected by the marine litter windrow. The percentage found in surface waters coincides with those found at beaches of the Canary archipelago by Herrera et al. (2018) and Campillo et al. (2021), where the majority MPs were also fragments and tar. A frequency of 47 % pellets was observed in beach samples from Famara (Herrera et al., 2018), whereas here, it only represented 0.5 % (Fig. 4a).

Regarding the size, most of the MPs found in our samples were < 1000 μm. Recent studies indicate that approximately 90 % of the microplastics in surface waters are <300 μm (Rist et al., 2020; Kuddithamby et al., 2023). Therefore, if we consider the small-size fractions not collected with the manta net, the total concentrations of microplastics (1 μm −5 mm) in surface waters of the Canary Islands are expected to be higher than those found here. The concentrations of MPs smaller than 200 μm in the water of the Canary Islands is still unknown. Future studies should address this knowledge gap, since these small fractions overlap in size with the phytoplankton and can be ingested by pelagic grazers (Rist et al., 2019; Rodríguez-Torres et al., 2020; Almeda et al., 2021).

In the present study, the most frequent colours found were white/transparent (52.6 %), black/dark (20.1 %), blue (8.2 %) and green (6.2 %) (Fig. 4b), similar to the colour composition of neustonic microplastics reported in other studies (Basurko et al., 2022). However, the frequency of colours in MPs found in stomach contents studies is different from the composition found in surface waters, suggesting an active/visual selection of microplastics based on their colour is used by some vertebrates, as observed in fish (Ory et al., 2017). Previous studies have found that blue microplastics are the predominant colour in the stomach contents of fish, marine mammals and turtles, followed by white/transparent, except in fish where the second most frequent colour was black (Ugwu et al., 2021). In contrast, the most frequent colour found in seabirds is transparent/white followed by blue (Ugwu et al., 2021). Blue is the predominant colour also in the studies focusing on jellyfish and fish in the Canary Islands (Herrera et al., 2019; Rapp et al., 2021; Reinold et al., 2021), while green is more common in seabirds due to the high presence of fishing lines of this colour (Navarro et al., 2023).

The most frequent type of polymer identified with FTIR was HDPE, which accounted for 65 % of the items analysed, followed by PP at 28 %, similar to the findings of other recent studies on floating microplastics (Adamopoulou et al., 2021). HDPE is mainly used to produce toys, shampoo bottles, milk bottles, etc.; while PP is used to produce food packaging, wrapping, microwave containers, etc. (Plastics Europe, 2021). These percentages correspond to the most produced plastic polymers globally, and at the European level (HDPE 12.9 % and PP 19.7 %), in the neustonic microplastics these percentages are even higher due to the low density of HDPE and PP (Plastics Europe, 2021). PE-LD is also one of the most produced polymers, but it is mainly used for the manufacture of bags and films, which makes them more sensitive to degradation in the sea, or to biofouling and sinking. The main polymers found also correspond to those most frequently found in biota studies, with PE being the most abundant, followed by PP (Ugwu et al., 2021). Moreover, the percentages of these polymers in our samples are very similar to those found in the study on microplastic ingestion in seabirds in Gran Canaria Island (71 % PE, 16 % PP) (Navarro et al., 2023).

The three most contaminated spots by marine litter at the sea surface were found in the leeward zones of Gran Canaria and Tenerife-La Gomera (ST8, ST8.2 and ST9) (Fig. 2). The reference values established for micro-litter in marine litter windrows are 10 micro-items per m^2 (Cózar et al., 2021). In our study, values higher than 17 micro-items per m^2 were found at station ST8 (Pasito Blanco; Gran Canaria), which corroborates the presence of a marine litter windrow. The formation of marine litter windrow requires the activation of convergence zones at the ocean surface and a high concentration of neustonic marine debris (Cózar et al., 2021). The Canary archipelago is characterized by its mountainous islands that act as an obstacle to the trade winds and the Canary Current. As a consequence, a wake is generated in the island's lee that can extend for kilometers. It is characterized by high surface temperatures since there is no agitation or water renewal in that area. Additionally, the island effect generates two eddies, one to the southwest and the other to the southeast of the island where they give rise to a divergent (upwelling) and convergent (subsidence) front, respectively (Arístegui et al., 1994; Hernández-León et al., 2007). Convergence processes will induce the formation of marine litter windrows in those regions with a particularly high concentration of debris at the sea surface, which, a priori, includes the macroscale accumulation zone of subtropical gyres (Law et al., 2010) or waters close to debris sources such as rivers and cities (Pedrotti et al., 2016). Therefore, the south of Gran Canaria is an area that meets the requirements for marine litter windrow formation, although it has not yet been sufficiently studied. The difference in MPs concentration between the two stations located in Pasito Blanco is likely due to the patchiness of plastic debris within the marine litter windrow. While one sample was collected in an area highly affected by marine litter windrow (ST8), the other station was located at its margin (ST8.2), at the interface with waters less impacted by marine debris at that specific moment. Station 8 and 8.2 are both located in the Mogán marine fringe, a "Special Conservation Zone" (ZEC, for its acronym in Spanish), belonging to the Natura 2000 Network. Its purpose is to ensure the long-term survival of vulnerable species and the most endangered natural habitats. Station 9 (Los Cristianos, Tenerife) is located within the Teno-Rasca marine fringe, also considered a "Special Conservation Zone" (ZEC).

In our study, the areas most affected by microplastic pollution coincide with special conservation zones. These areas are home to incredible biodiversity that is being affected by plastic pollution, especially by ghost nets, drifting buoys, and ingestion of microplastics. These areas have significant importance for the protection of these marine organisms, some of them protected as vulnerable or endangered species, such as loggerhead turtles (*Caretta caretta*), green turtles (*Chelonia mydas*), bottlenose dolphins (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphins (*Grampus griseus*), short-finned pilot whales (*Globicephala macrorhynchus*), sperm whales (*Physeter macrocephalus*) or Cory's shearwaters (*Calonectris borealis*). These majestic animals are all vulnerable to this type of pollution, as they become entangled, suffocate, or ingest a large amount of microplastics (Herrera et al., 2019; Navarro et al., 2023; Pham et al., 2017; Ugwu et al., 2021; Wright et al., 2013).

The highest concentrations of zooplankton were found in the convergence zones where marine litter windrows form, as has been observed in previous studies by Gove et al. (2019) showing that the "surface slicks" concentrate fish larvae, zooplankton, and phytoplankton (Fig. 6b). In a previous study the microplastics/zooplankton dry weight ratio in an accumulation zone was 2 ± 1.3 (Herrera et al., 2020), which is even higher than the one found in this study. High MPs/zooplankton ratios indicate a higher risk of exposure to microplastics and associated chemical pollutants in marine biota feeding on these plastic accumulation zones. This increase in exposure to MPs and its pollutants, increases the vulnerability and risk to organisms due to MPs.

Copepods are the most abundant taxonomic group within zooplankton in the Canary Islands, representing 80 % of this region's total abundance of organism (Gómez and Hernández-León, 1997; Hernández-León et al., 2007). We found a higher percentage of copepods for most stations, with 54 % in the total samples, making it the predominant taxonomic group. However, in the south of Tenerife (ST8 and ST8.2), La Gomera (ST11), Alegranza (ST14 and ST14.2), and El Hierro (ST15 and ST15.2), the results do not agree with those reported by Gómez and Hernández-León (1997) and Hernández-León et al. (2007). Precisely, at these stations, more fish eggs and larvae than copepods were found. Other authors have observed that convergence zones where microplastics accumulate, such as stations ST8 and ST8.2, are also areas of larval fish aggregation (Gove et al., 2019), attracting planktivorous fish and their predators.

In addition, organisms such as large filter-feeding marine mammals (genus Balaenoptera or *Megaptera novaeangliae*), whale sharks (*Rhincodon typus*) and oceanic manta rays (genus Mobula) live and feed in the region studied (Carrillo et al., 2010; Espino et al., 2014; Prieto et al., 2014, 2017). Hence, our study also highlights the potential impact on filter-feeding organisms, as they could ingest a high percentage of microplastics in the marine litter windrows (Fig. 6b).

Marine litter windrows in the Canary Islands, not only transport a large number of plastics and zooplankton, but also part of the marine phanerogam *Cymodocea nodosa* (Fig. 6a). Turtles are particularly vulnerable to these litter structures, as they feed on marine phanerogams and are frequently found entangled in fishing gear (Fig. 6c).

Future studies are needed to localise marine litter windrows, as well as to predict where they might be forming, to determine their location and focus monitoring in these areas. Interesting studies are being carried out in this regard. "Windrows As Proxies" project (WASP) proposes the use of Copernicus Sentinel-2/MSI images to identify filaments of floating marine debris (Arias et al., 2021). Marine litter windrows occupy relatively small areas in the ocean, but they can accumulate >90 % of marine debris (Gove et al., 2019). These authors showed that the mean densities of phytoplankton, zooplankton and fish larvae were 1.7, 3.7 and 8.1 times higher, respectively, in marine litter windrows than in areas where they are not present, therefore is probable that planktivorous fish are feeding in these accumulation zones, as well as their predators: sharks, cetaceans and turtles. Studying the formation, evolution and concentration of these filaments allows us to advance in the knowledge and management of marine litter pollution, to keep track of it and identify the origin of the litter. Entanglement prevention tasks should focus on these areas, especially in the south of Tenerife and the south of Gran Canaria, where the Special Protection Zones, ZEC Teno-Rasca marine fringe and ZEC Mogán marine fringe respectively, are

Fig. 6. a) Marine litter windrow. b) Sample collected in ST8 in the south of Gran Canaria where a high percentage of fish larvae and copepods, together with fragments of microplastics, are observed. c) Turtle entangled in a fishing net found in a marine litter windrow in the south of Tenerife.

located.

5. Conclusions

Microplastics were present at all stations but in highly variable concentrations, with concentrations ranging from 0.27 to 136.7 per cubic meter. The most contaminated station was ST8 due to the presence of a marine litter windrow. These marine debris accumulation lines also concentrate fish larvae and copepods, and therefore represent a danger to planktivorous organisms and their predators, which suffer the effects of ingestion and entanglement. More studies are needed to localise marine litter windrows by radar or satellite images, in order to concentrate efforts to clean up and rescue marine fauna.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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CRediT authorship contribution statement

A.C. and A.H. collected and processed the samples, analysed the data, performed statistical analysis and graphics with R, and wrote the original draft. R.A and A.V. collected the samples, reviewed and edited the article. M.G and I.M. contributed to the funding, reviewed and edited the article. A.N. analysed the samples by FTIR and reviewed the article.

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