Marine Pollution Bulletin 153 (2020) 110967

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Study of plastic pollution and its potential sources on Gran Canaria Island beaches (Canary Islands, Spain)

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ARTICLE INFO

Keywords:
Microfibres
Plastic pollution
Sewage discharges
Beaches' Canary Islands

ABSTRACT

In order to understand the origin of plastic debris pollutants that accumulate in the Canary Islands coastline, six beaches of Gran Canaria Island were studied during different seasons to estimate the abundance and the types of two microplastics fraction sizes (0.01–1 mm and 1–5 mm) and mesoplastics fraction (5–25 mm).

For the larger fraction of microplastics and mesoplastics, a high percentage of fragments and foams were found; moreover, both fractions show the same accumulation pattern in relation with the wave, wind, and current. The debris was checked for exogenous and local origins. Moreover, for the smaller fraction of microplastics, only natural, semi-synthetic, and synthetic fibres were found, showing a totally different spatial distribution from the others fractions. This result suggests a possible endogenous origin of the contamination, in relation to the type and amount of wastewater discharges and beach users.

1. Introduction

Globally, > 360 million tons of plastic waste was produced in 2018 of which between of 2 and 5% end up in the sea (Jambeck et al., 2015) mostly by rivers (Lebreton et al., 2017). Eriksen et al. (2014) estimated that 5.25 trillion particles of plastic debris are floating on sea surface.

During their oceanic migration, the floating litter tends to migrate to oceanic margins, accumulates in subtropical gyres (Moore et al., 2001; Cozar et al., 2014; Eriksen et al., 2014; Van Sebille, 2015; Lebreton et al., 2017), or deposits on the coasts (Derraik, 2002; Herrera et al., 2018a). Therefore, it is of great interest, not only to the scientific community but also the rest of the society, to learn more about plastic wastes that contaminates the ocean, especially microplastics (MPs), their associated chemical pollutants (Camacho et al., 2019; Hirai et al., 2011; Ogata et al., 2009; Van et al., 2012), and their behavior in marine trophic webs (Carbery et al., 2018; Rochman et al., 2013).

The Canary Islands, located in the oriental margin of the Atlantic Ocean and in the middle of the influence of Canary Current, have been shown to receive large amounts of exogenous plastic waste. Previous studies by Baztán et al. (2014), Herrera et al. (2018a) and Reinold et al. (2020) found out that the predominantly northern (N) and northeastern (NE) directions of wind, waves, and currents tend to accumulate marine debris on north and east beaches' coast registering maximum concentrations of around 300 g/m^2 on the northeastern coasts of eastern island and showing high concentrations of chemical pollutants (Camacho et al., 2019). The main polymers of these plastics are polyethylene, polypropylene, and polystyrene (Álvarez-Hernández et al., 2019; Edo et al., 2019), and, as demonstrated in this study, are being ingested by local fishes (Herrera et al., 2019).

However, not all the plastic material that reaches the Canary Islands is of exogenous origin. There is evidence that there are certain types of MPs that are being discharged into the sea and therefore could be endogenous contamination. It has been demonstrated in other regions that MPs, in particular the microfibres (MFs), are being spilled into the marine environment through wastewater discharges (Browne et al., 2011) because the standard treatments applied to wastewater are not effective in the retention of MFs, especially with the smaller fraction (< 1 mm) (Prata, 2018). There are evidences that the secondary treatment of wastewater retains 99% of the MPs (Heinonen et al., 2017). Given this situation, if a wastewater discharge has a considerable daily flow, it could be considered that the remaining 1% could become a polluting vector of plastic of great importance for marine ecosystems. Nevertheless, in the case of Canary Island, this scenario is even worse due to the fact that a significant amount of wastewater is discharged directly without treatment. Only the outflows of the main urban nucleus are treated.

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https://doi.org/10.1016/j.marpolbul.2020.110967
Received 24 October 2019; Received in revised form 5 February 2020; Accepted 6 February 2020

Nevertheless, there are other pollution vectors of this type of MPs that could be affecting their accumulation on the coasts, the runoff from the rivers that flow into the seas (ravines in the case of the Canary Islands, since there are no permanent rivers), the users who frequent the beaches and transport MFs in their clothing, and most importantly, the air transport of these light MFs (Henry et al., 2019). Perhaps for this reason, the MFs are the most common secondary MP in sandy beach sediment (Barnes et al., 2009; Villiers, 2018), and appear recurrently in the stomachs of large numbers of marine organisms (Bottari et al., 2019; Herrera et al., 2019; Wang et al., 2019). They are also being transported by aerial insects who act as a polluting bridge between the terrestrial and marine environment (Al-jaibachi et al., 2018).

Therefore, first, the present study aims to determine the quantity and the composition of two fraction size of MPs, 10 μm–1 mm and 1–5 mm, and mesoplastics (MEPs), 5–25 mm (Arthur et al., 2009; Lee et al., 2013), that accumulated in along the four seasons of 2018 on the coasts of Gran Canaria Island. The second aim is to study the spatial variability in order to find the sources of this marine waste. Focusing on the smaller fraction of MPs (< 1 mm) and the possible effects of wastewater discharges in the MFs distribution.

2. Materials and methods

2.1. Study area and anthropogenic impacts of the beaches

Taking into account the oceanographic factors and the physical characteristics, mentioned in Table 1, beaches distributed evenly along the entire coastline of the Gran Canaria Island were chosen (Fig. 1).

Most of the studied beaches were selected within the northeast coast in function of the predominant direction of wind, wave, and current: Bocabarranco (A), La Cicer (B), La Laja (C), and Cuervitos (D). The beaches Del Águila (E) and Veneguera (F), located on the southern slope of the island, were selected as control (Fig. 1).

To select the study beaches, a number of general characteristics have been predetermined. The select beaches must have enough sand to allow sample collection, easy access to the beach for monitoring, great capacity to retain marine litter according to its location and orientation, and easy data collection as well as characterization of the main local pollution vectors assumed for all the beaches.

The main local pollution vectors assumed for the beaches were the presence of sewage discharges, the anthropogenic pressure, ravine, and airborne contamination among others.

The anthropogenic pressure on the beaches has been described qualitatively (low, medium, or high) according to the number of inhabitants close to the beach, number of visitors according to statistics of the Canary Government data published. Therefore, as shown in Table 1, La Cicer (B) and Del Águila (E) have high levels of anthropogenic pressure. For the other beaches, no data was found but La Laja (C) and Bocabarranco (A) had visitors only in the summer and, on the other hand, Cuervitos (D) and Veneguera (F) were far from urban centres and therefore access was difficult.

To determine the relationship between MP accumulation and the sewage outflows, the wastewater discharges near the sampled beaches were located and characterized from the Canary Government data published in the GRAFCAN website. For this study, the outflows located closer than 5 km from the beaches were examined. A total of 35 wastewater discharges were studied (Table S2, Supplementary data). According to the number of outflows and the distance to the study area and flow, La Cicer (B), Cuervitos (D) and Veneguera (F) beaches were considered as control beaches regarding the influence of wastewater discharges. These beaches have a low number of wastewater discharges compared to the rest.

2.2. Field work

For each fraction, a total of three samples in three different areas of the beach were collected in each of the four seasons during 2018, always coinciding with the highest tide coefficient periods. Therefore, a total of 12 replicates were collected for each beach.

In the present work, the methodology proposed in the protocol developed by Herrera et al. (2018b) was applied, following the guidelines recommended by Besley et al. (2017) and MSFD GES Technical Subgroup on Marine Litter (2013) for MP beach monitoring.

However, this process was different for the larger fraction (> 1 mm), MPs 1–5 mm and MEPs, one used for than the smaller fraction (< 1 mm), MPs 0.01–1 mm.

For the larger fraction, the surface layer (about 1 cm) of the sediment was removed with a metal spoon. The sample obtained was placed in a mesh bag with an opening of 1 mm. The mesh was rinsed so that the sand was removed, and all the material > 1 mm was retained. Then, in the laboratory, 100 mL of 96% ethanol was added to the samples in order to separate plastics from rest of land plants, algae, and seeds by density. These natural organic materials remained on surface while the sand and plastic debris sank. In the presence of sediment, 100 mL of saturated NaCl solution (358.9 g/L) was added to separate the plastic material that remained on the surface while the sediment sank.

The samples were sieved and separated by fraction 1–5 mm and 5–25 mm. Data were standardized in concentration of plastics per square meter (number of items/m^2) and grams of plastics per square meter (gr/m^2) was obtained for each fraction, and the total percentage of colors and types was determined. Among the most common types of plastics in the oceans, 5 major groups have been distinguished: fragments, fibres, foams, films, and pellets (Rezania et al., 2018), among others, as shown in Fig. 2.

For the smaller fraction, a sub-sample of 50 mL of sediment was collected with a metal spoon and stored in a sealed container for further

Table 1
General characteristics of the beaches studied.

	Bocabarranco (A)	La Cicer (B)	La Laja (C)	Cuervitos (D)	Del Águila (E)	Veneguera (F)
Localization:	NW	NNE	NE	E	SE	SW
Latitude	28°9′29.20″N	28°7′57.03″N	28°3′24.41″N	27°52′47.49″N	27°46′32.33″N	27°50′48.51″N
Longitude	15°39′55.49″W	15°26′38.23″W	15°25′4.26″W	15°23′25.22″W	15°31′43.68″W	15°47′28.84″W
Direction	NNW	NW	NE	NE	SSE	SW
Anthropogenic pressure:	Medium	High	Medium	Low	High	Low
Users	No	Yes	No	No	Yes	No
Urban	Yes	Yes	Yes	No	Yes	No
Outflows	Yes	Yes	Yes	Yes	Yes	Yes
No. related outflows	5	3	11	2	10	3
Cleaning	No	Yes	No	No	Yes	No
Mouth of a ravine	Yes	Yes	No	No	No	Yes
Total longitude	240 m	2949 m	1270 m	100 m	430 m	340 m
Intertidal width in sampling area	30 m	20 m	25 m	20 m	20 m	10 m
Sediments:	Sand and boulders	Sand	Sand	Sand	Sand and boulders	Sand and boulders

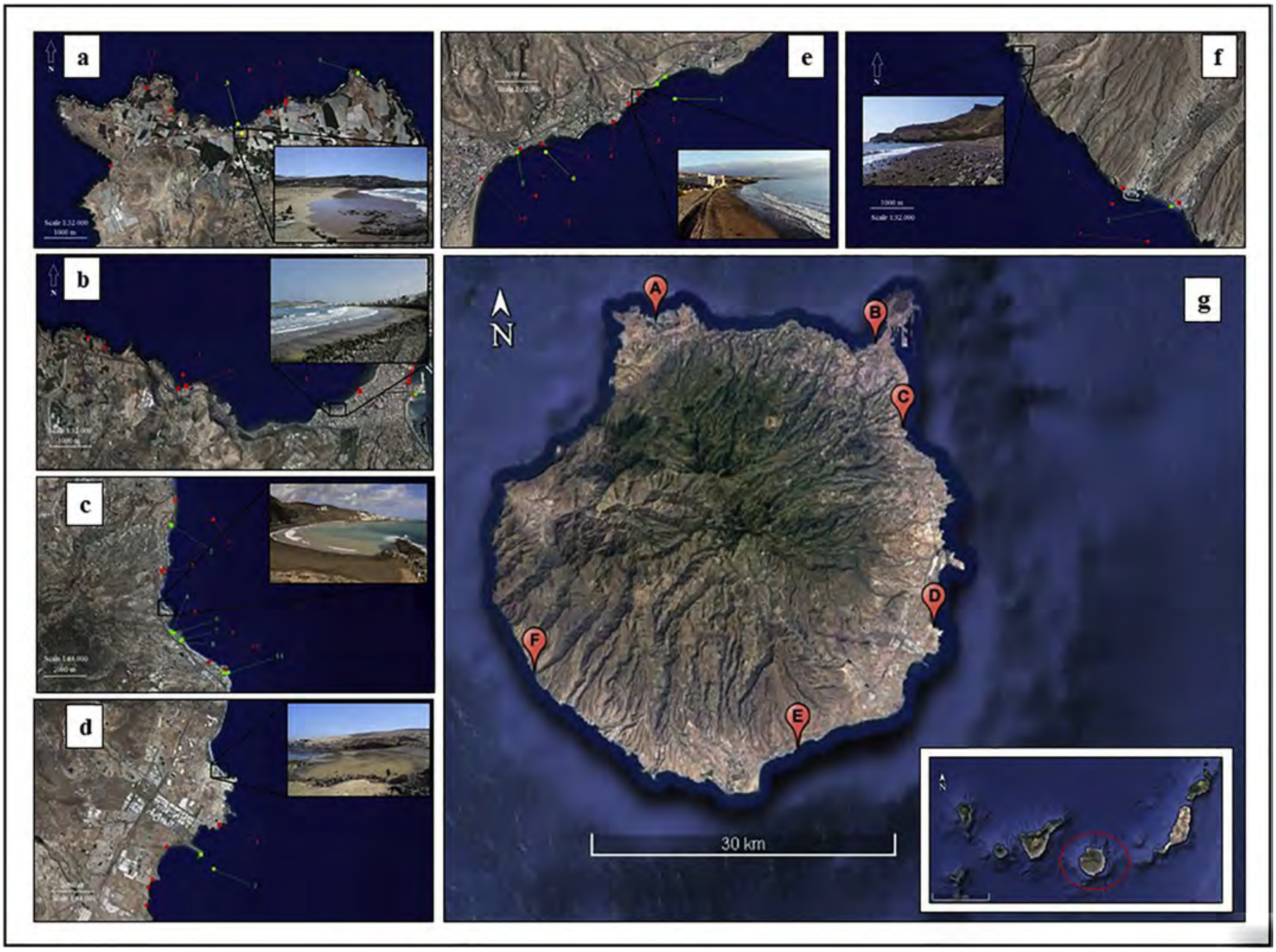

Fig. 1. Sampling areas and related outflows: a) Bocabarranco beach (A); b) La Cicer beach (B); c) La Laja beach (C); d) Cuervitos beach (D); e) Del Águila beach (E); f) Veneguera beach (F); g) Gran Canaria Island. The beaches studied: each outflow was identified by a number and described in a color according to its administrative status: red, if the wastewater discharge was not authorized; yellow, if it was in process; and green, if it was authorized. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

processing. The 50 mL sample were placed in a 500 mL beaker and 200 mL of saturated NaCl solution (358.9 g/L) was added; then it was stirred for 20 min at 600–700 rpm and left to decant for 24 h. Once the sedimentary material is completely decanted at the bottom of the beaker, the water was extracted by siphoning. Finally, the water removed was filtered with a polycarbonate filter of 10 μm of pore. As proposed in the protocol by Herrera et al. (2018b), the precautionary measure for contamination was done: the whole process was carried out inside the fume hood, with 100% cotton gown, gloves, and mask. For greater caution, all of the material was washed by bi-distilled water. Moreover, during the processing, an open petri dish with a wet filter was put to check the airborne contamination inside the fume hood. Then, these filters were analyzed.

Subsequently, the filters were inspected under a binocular stereomicroscope (Leica S9i with integrated CMOS camera).

Finally, for this fraction, data was only extrapolated by concentration of plastics per square meter (no. of items/m^2) according to the volume of sand processed (50 mL). The total percentage of colors per beach was also determined.

2.3. Statistical analysis

The number size categories of MPs and its weight were summarized as mean ± sd, minimum and maximum values.

A negative binomial regression model was used to assess the effects of location and season on the number of MPs found. This model is adequate when the response variable is over dispersed count data, as was in this case where the variance of the number of MPs in each beach and season exceeded the mean. Significant effects of location and/or season were tested using ANOVA Likelihood Ratio test. When significant effect was detected, Tukey's Test was performed to determine which beaches/season had differences between them.

Data obtained for 35 wastewater discharges were analyzed (Table S2, Supplementary data). Then, a number of “simplifications” were made beforehand, taking into account the following exclusion criteria: wastewater discharges with a lack of information according to their flow and/or with non-continuous discharges were discarded.

Afterwards, a descriptive analysis was carried out in order to characterize the beaches in terms of the type, distance, and volume of wastewater discharges. For this, the distance of the wastewater discharges from the study area and the wastewater discharges flow (m^3/h) were considered for each effluent type (urban, industrial, or brine), thus having six explanatory variables measured at each beach. In order to simplify the interpretation of these variables, a Principal Component Analysis was used with the variables first standardized to mean 0 and standard deviation 1 for taking into account the relative importance of

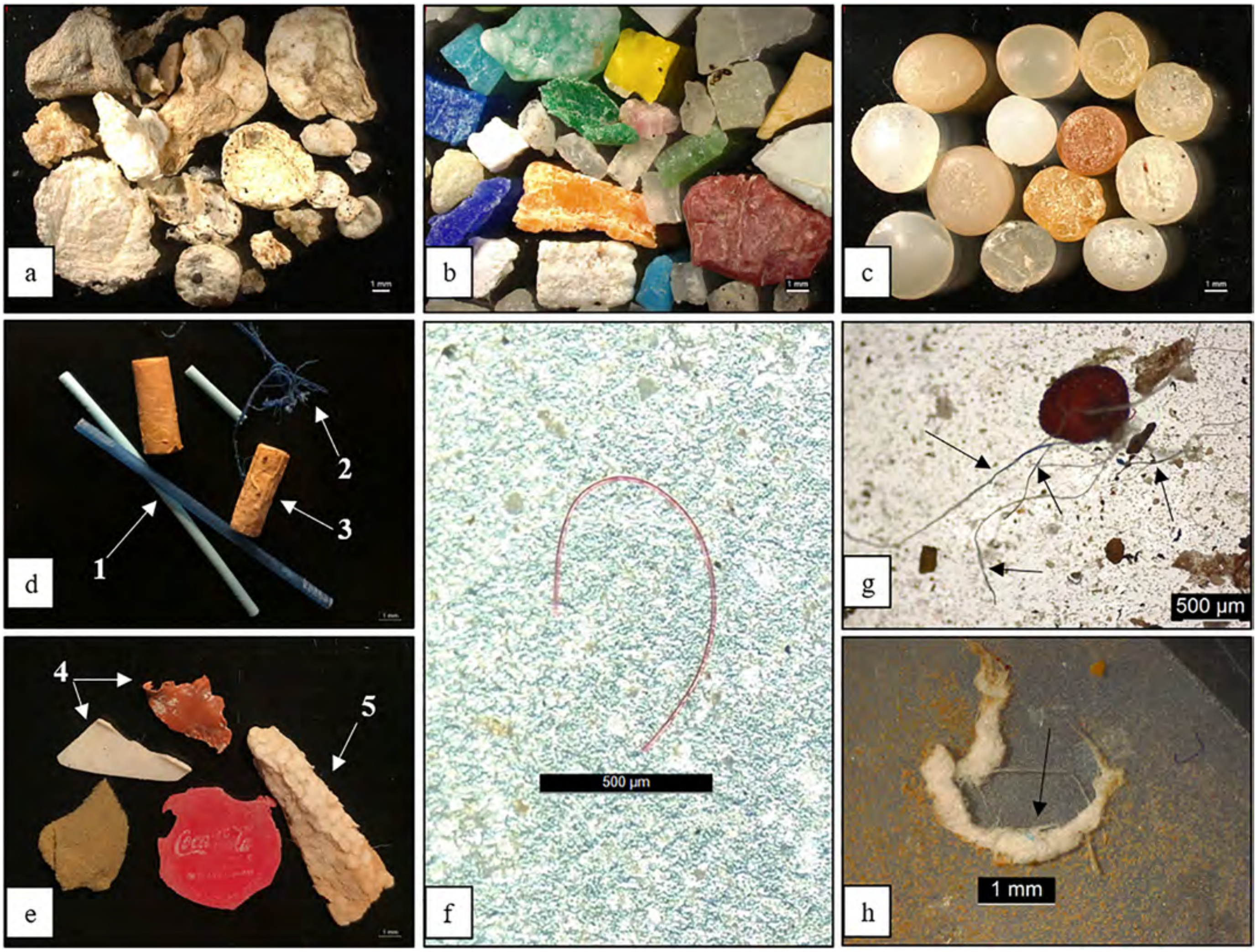

Fig. 2. Examples of the plastic debris sampled. For the larger fraction of MPs (1–5 mm): a) foams; b) fragments; and c) resins pellets. For the MEPs (5–25 mm): d) ear sticks (1), line (2) and cigarette butt (3); e) fragments (4) and foams (5). For the MFs (10 µm–1 mm): f) a clear example of red MF; g) MFs; h) sometimes, MFs were found in clusters.

its values between the different beaches and avoid the effect of the different measurement scales.

The data was processed using the R Version 6.1.1 with RStudio Version 1.2.1335.

3. Results

3.1. Composition and colors

For the smaller fraction (MPs 0.01–1 mm), only MFs were found. Quantification was made by visual inspection and the samples were not analyzed by FTIR (Fourier-transform infrared spectroscopy). Therefore, not all MFs analyzed were plastic debris; there was probably a percentage of natural and semi-synthetic fibres (Kroon et al., 2018). For this reason, it is necessary to specify that here when referring to MFs, natural, semi-synthetic and non-synthetic fibres should be included.

Most of the MFs found were transparent (49.2%), although a high percentage of blue MFs were also found (36.5%) (Fig. 3.a).

As shown in Fig. 4, for the larger fractions, (MPs 1–5 mm and MEPs), most of the items were fragments from other bigger plastic pieces, reaching 61.3% in larger MPs (1–5 mm) and 80.2% in MEPs (5–25 mm). Furthermore, a high percentage of resin pellets (13.7%) and ear sticks (2.9%) were found. These results are relevant in the explanation of the origin of this marine litter. On the other hand, for this fraction size, most of the items were white (Fig. 3.b and .c) due to the high percentage of foams found.

3.2. Spatial and temporal variability

As shown in Table 2, the concentrations of MP and MEPs were very different between the study zones. In general, the replicates showed large differences in concentration, as can be observed in the high values of the standard deviation.

For the smaller fraction (MFs), Del Águila (E) and La Cicer (B) showed the maximum values of concentration, while for the larger fraction, MPs (1–5 mm) and MEPs (5–25 mm), the maximum values were found in Cuervitos (D). For all fractions, Veneguera (F) showed the minimum values.

In the three fractions analyzed, there were significant differences ($p < 0.05$) between locations (contrast details in Table S1, supplementary). As shown in Fig. 4.a, the MFs obtained a more homogeneous accumulation pattern throughout the year, both between and within beaches. In contrast, the two larger fractions (> 1 mm) obtained a more heterogeneous distribution between beaches and a more accentuated dispersion between replicates.

In addition, comparing data obtained for the MFs with the values obtained for the other two fractions (Table 2), we can observe a clear difference in the pattern of accumulation of marine debris on the island.

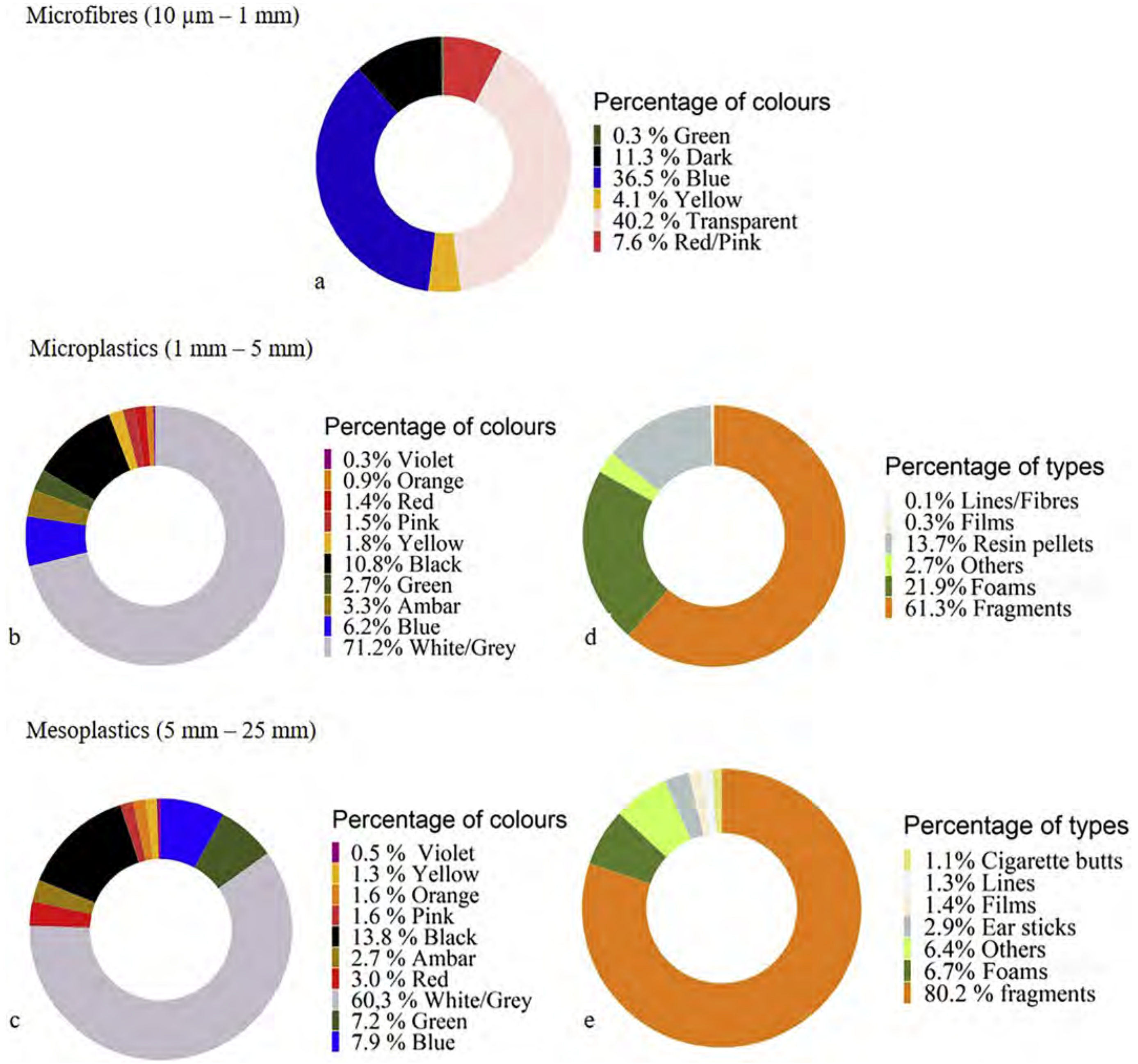

Fig. 3. Percentage of colors for each fraction: a) MFs; b) MP (1–5 mm); c) MEP (5–25 mm). Typology of the total items sampled: d) MP c (1–5 mm); e) MEP fraction (5–25 mm).

This pattern was similar between the two major fractions analyzed, larger MPs (1–5 mm), and MEPs (5–25 mm). This result can be seen more clearly in the maps of the island with the distribution of annual average concentration (Fig. 4d to f). As predicted, the accumulation pattern for these fractions is a function of the predominant wind, wave, and current directions, with maximum concentrations distributed on the north and northeast coast. Nonetheless the MFs don't follow this accumulation pattern, warning that something different is happening with this fraction.

In the three fractions analyzed, there were significant differences too ($p < 0.05$) (see details in Table S1). Nonetheless, no clear seasonality patterns were observed, probably due to the low number of observations. In the case of MFs, during autumn, the beaches showed a pattern of accumulation higher compared to the rest of the seasons while in MPs fraction 1–5 mm was significantly higher in winter. For MEPs, there were no significant differences between the seasons.

3.3. *Characterization of wastewater discharges*

From the 18 wastewater discharges analyzed, 11 were not administratively authorized, 9 had no treatment, 8 had secondary treatment, and only 1 had tertiary treatment.

The database obtained is shown in Table 3 and the calculated total flow rate (*FTot*) of all wastewater discharges related to each beach has been calculated. Based on this, the proportion that would correspond to each wastewater discharge has been calculated according to the nature of the effluent; obtaining partial flow rates as follows:

Partial flow rate, proportion of the flows of wastewater discharge of brine (*FBrine*), industrial (*FIndW*) or urban (*FUrbW*) wastewater in m^3/h:

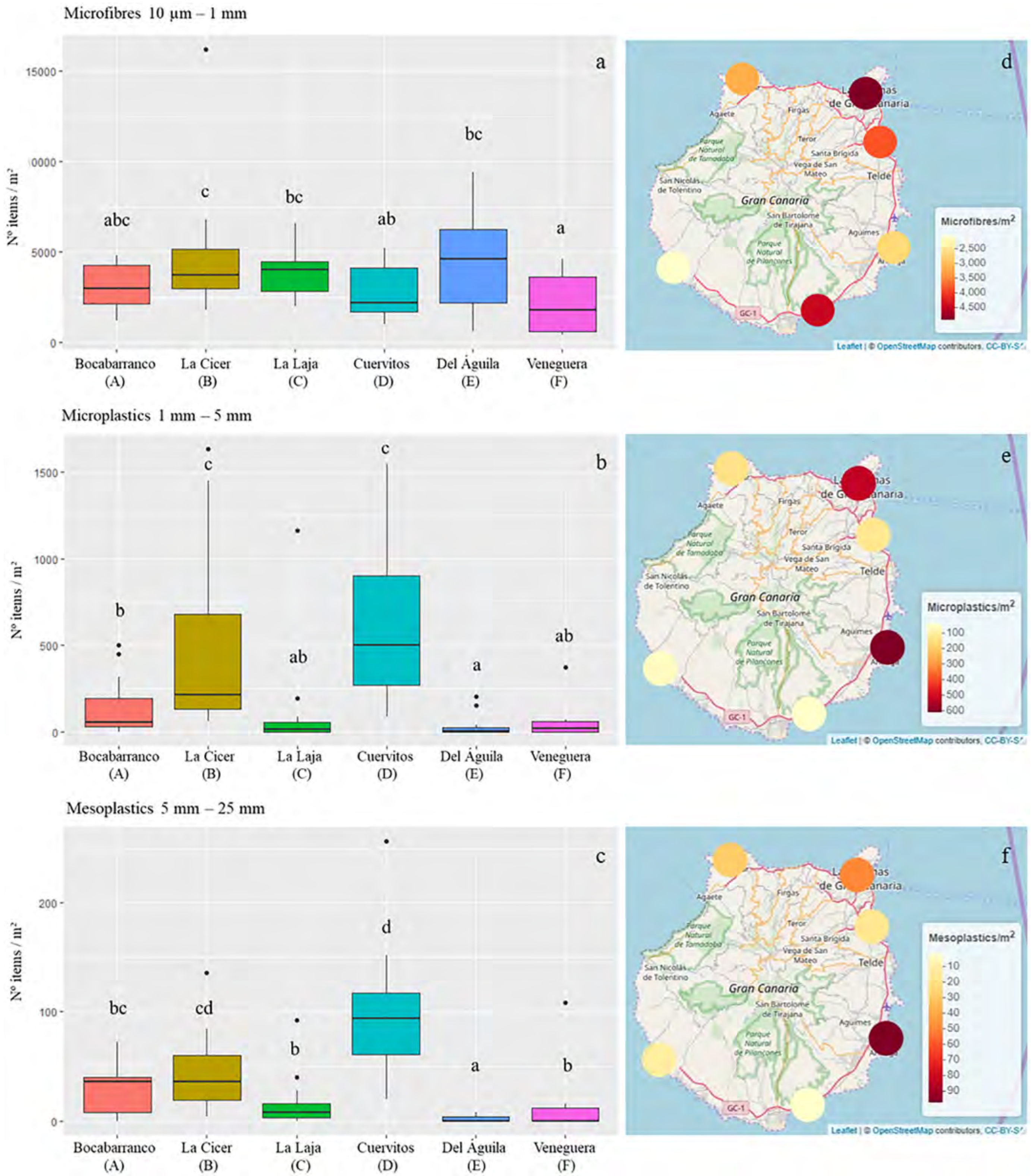

Fig. 4. Annual median concentrations of debris representing in a boxplot (a, b, c) and the annual average concentration represented on a map of Gran Canaria Island (items/m^2) (d, e, f), for each studied beach.

Partial Flow rate

$$= \frac{\sum_{i=1}^{Parcial\ flow} Flow\ rate\ of brine\ or\ industrial\ or\ urban\ wastewater\ discharges}{Ftot}.$$

Total flow rate ($Ftot$) in m^3/h:

$$Ftot = \sum Parcial\ flow\ rates = \sum FBrine + FIndW + FUrbW$$

In addition, the average distance of the set of wastewater discharges in each beach was calculated: *DBrine*, *DUrbW*, and *DIndW* (average distance of wastewater discharge of brine/industrial/urban wastewater in km).

Table 2

Mean values (± standard deviation) obtained at each sampling location, maximum (Max.) and minimum (Min.) annual concentrations (items per square meter and grams per square meter) for each fraction.

Microfibres (10 μm–1 mm):

Beach	Mean ± SD	Max.	Min.
	No. items/m^2	No. items/m^2	No. items/m^2
Bocabarranco (A)	3166.7 ± 1208.5	4800.0	1200.0
La Cicer (B)	4900.0 ± 3824.8	16,200.0	1800.0
La Laja (C)	3816.7 ± 1271.9	6600.0	2000.0
Cuervitos (D)	2766.7 ± 1439.3	5200.0	1000.0
Del Águila (E)	4433.3 ± 2647.6	9400.0	600.0
Veneguera (F)	2083.3 ± 1529.0	4600.0	400.0

Beach	Mean ± SD	Max.	Min.	Mean ± SD	Max.	Min.
	No. items/m^2	No. items/m^2	No. items/m^2	g/m^2	g/m^2	g/m^2
Microplastics (1–5 mm):						
Bocabarranco (A)	148.3 ± 176.8	504.0	0.0	1.3 ± 1.7	5.8	0.0
La Cicer (B)	527.3 ± 597.3	1632.0	60.0	4.0 ± 4.8	13.7	0.3
La Laja (C)	130.7 ± 330.3	1164.0	0.0	1.9 ± 3.4	11.9	0.0
Cuervitos (D)	607.3 ± 429.2	1544.0	88.0	7.5 ± 6.3	19.5	0.2
Del Águila (E)	36.3 ± 68.9	204.0	0.0	0.2 ± 0.4	1.2	0.0
Veneguera (F)	54.3 ± 103.9	372.0	0.0	0.4 ± 0.9	3.3	0.0
Mesoplastics (5–25 mm):						
Bocabarranco (A)	29.3 ± 22.1	72.0	0.0	4.1 ± 3.6	12.4	0.0
La Cicer (B)	50.0 ± 45.9	136.0	4.0	2.9 ± 3.0	7.5	0.0
La Laja (C)	17.3 ± 26.4	92.0	0.0	2.1 ± 2.0	6.1	0.0
Cuervitos (D)	97.0 ± 64.3	256.0	20.0	13.1 ± 9.6	32.8	0.5
Del Águila (E)	1.7 ± 2.7	8.0	0.0	0.05 ± 0.1	0.4	0.0
Veneguera (F)	13.0 ± 30.5	108.0	0.0	1.3 ± 3.1	10.6	0.0

To carry out the Principal Component Analysis, first, the explanatory components were centralized and scaled (flow rate, distance and nature of the wastewater discharges) because their values vary.

The two first principal components accounted for 72.3% of the total variance. Fig. 5 shows that the first component (PC1) is a contrast between *FBrineW and DBrineW*, and *DurbW*, *DindW*, and *FindW*; this could be interpreted as if the values decrease in this axis (values to the left), greater influence of the brine wastewater discharges, and vice-versa. In other words, Del Águila beach (E) was characterized by being influenced mostly by brine wastewater discharges than the other beaches, while Cuervitos beach (D) had no influence of this wastewater and was also characterized by presenting the greatest distances from their related outflows (Table 3). The second component (PC2) represented the importance of *FUrbW* inside of total flow rate (*FTot*): high values on this axis would indicate that almost all of the flow is of urban wastewater discharges, while low values would indicate greater presence of flows of other types. Then, La Cicer (B) was seen as clearly influenced by urban wastewater discharges while La Laja (C), despite obtaining the highest *FTot*, did not show a predominant influence of one type of wastewater.

4. Discussion

Here, for the first time, the variation in MP and MEP accumulation along the coast of Gran Canaria was monitored. Furthermore, this is the first study to investigate the quantity of MPs in the fraction of 0.01–1 mm accumulated on the beaches of the Canary Islands.

For the largest fraction of plastics (1–5 mm and MEPs), both the concentrations and the typology of the residues found were similar to the main groups of plastic residues recorded in several studies carried out over the world (Rezania et al., 2018) and in the Canary Islands (Baztán et al., 2014; Herrera et al., 2018a; Reinold et al., 2020).

Most of the items found for these fractions were fragments from larger plastic pieces. The study by Eriksen et al. (2014) found out that most of the floating macroplastic in the oceans was polystyrene foam and abandoned fishing buoys, which explains the high values found for this group. In addition, it also explains why most of the residues for both fractions were white or grey-ish in color, which is the characteristic of EPS and XPS (Fig. 3b, c).

The origin of both types could be both exogenous and endogenous to the island. However, there is evidence to support the idea that a large percentage of these marine debris are brought in by marine currents; proof of this are the large quantities of resin pellets found, expressed by

Table 3

The database obtained for the characterization of the variables defined for the wastewater discharge for each beach.

Beach	*FBrine*	*DBrine*	*FUrbW*	*DUrbW*	*FIndW*	*DIndW*	*FTot*
	m^3/h	km	m^3/h	km	m^3/h	km	m^3/h
Bocabarranco (A)	0.25	2.32	0.75	0.18	0.00	0.00	1327.14
La Cicer (B)	0.00	0.00	1.00	3.60	0.00	0.00	23.50
La Laja (C)	0.11	2.53	0.09	3.50	0.87	1.60	28,300.30
Cuervitos (D)	0.00	0.00	1.00	5.40	1.00	5.40	355.00
Del Águila (E)	0.79	2.09	0.36	2.49	0.00	0.00	1398.00
Veneguera (F)	0.15	5.60	0.85	4.30	0.00	0.00	75.30

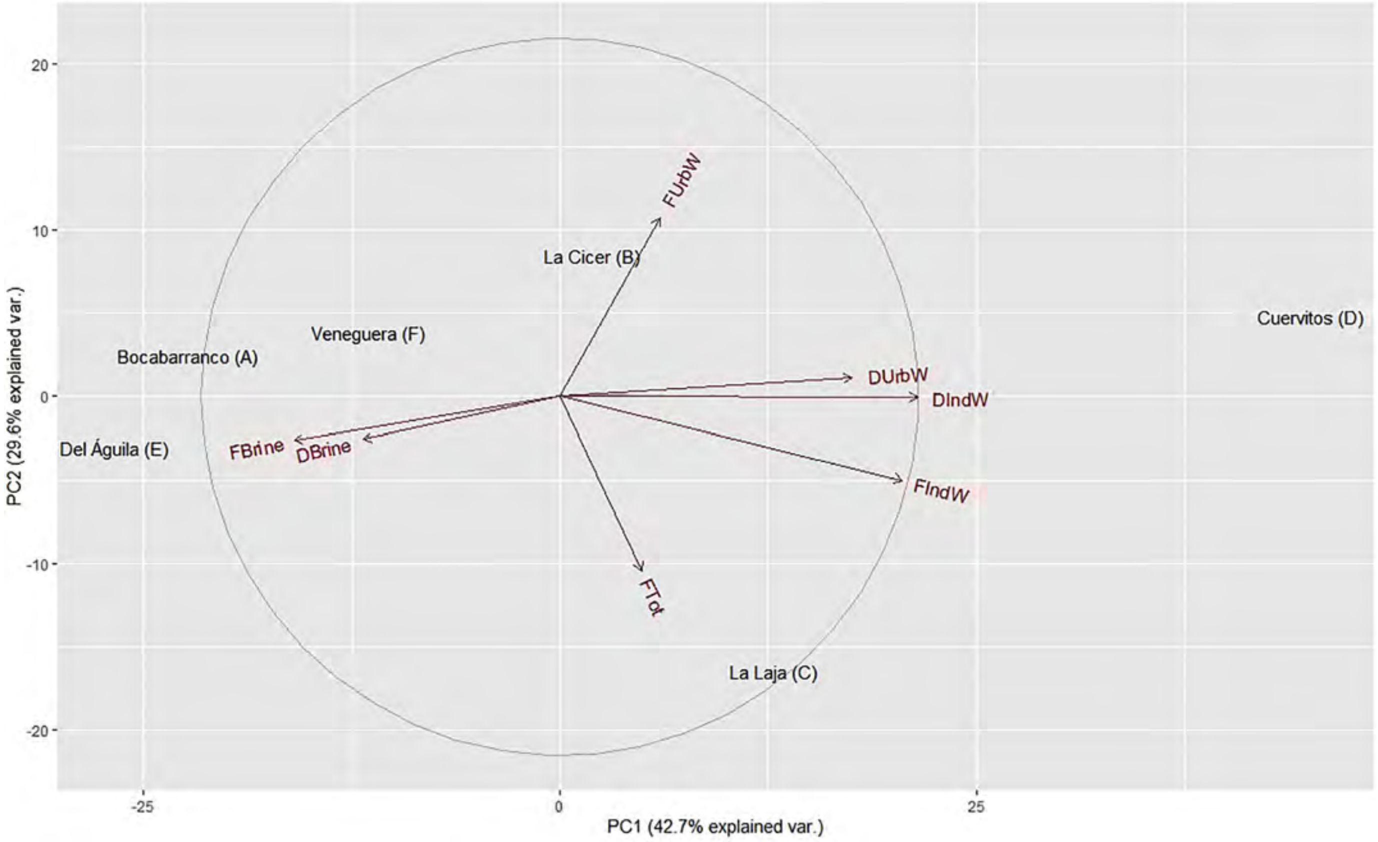

Fig. 5. Graph representing jointly the sampling locations and explanatory variables named versus the two principal components.

the larger fraction of MPs (1–5 mm). There is no big plastics industry in the Canary Islands that uses these raw materials. Therefore, it can be concluded from the results that the Canary Islands are receiving a large amount of exogenous pollution through the Canary Current (Van Sebille et al., 2012). Proof of this is the large amount of resin pellets found in Lambra beach (in La Graciosa island) and Famara beach (in Lanzarote island) situated in the northeast coast of the archipelago (Herrera et al., 2019). This hypothesis was reinforced by the high percentage of yellowish/amber-colored and arrested pellets collected (Figs. 2.c, 3.b), a sign that they had been floating for long periods of time in the sea, as explained by Camacho et al. (2019). The coloring and the amount of chemical contaminants acquired were directly related to the floating time of resins pellets in the ocean.

However, the MEP fraction showed a high percentage of cotton bud sticks around (Fig. 3.e). The source of this type of plastic waste is related to the poor wastewater management and could be endogenous contamination (Veiga et al., 2016).

Patterns of both fractions larger than 1 mm showed that the beaches located between northern and eastern coasts (Fig. 4.a, b, c), Bocabarranco (A), La Cicer (B), and Cuervitos (D) presented the highest average concentrations, while the beaches located on the southern slope, Del Águila (E), and Veneguera (F) presented the lowest concentrations (Table 2). These results are in line with those obtained in the studies carried out by Baztán et al. (2014) and Herrera et al. (2018a), which concluded that the quantity and distribution of these fractions in the Canary Islands is determined by the predominant wind and wave directions (north and northeast) and the Canary Current (northeast). The statistical analysis verified that in the concentrations of the larger fraction there were significant differences between the beaches (p-value < 0.05), specifically between Bocabarranco (A), La Cicer (B), and Cuervitos (D) and the beaches proposed as control, Veneguera (F) and Del Águila (E), (Fig. 4). This supports the hypothesis about the exogenous origin of these wastes.

However, for MFs, the pattern of accumulation was found to be different (Fig. 4). In this case, the accumulation pattern in function of currents, waves, and wind is not clear. This variation in the distribution of average concentrations raises the idea that MFs tend to accumulate differently from larger plastics. The cause of this could be explained by several hypotheses, depending on the origin.

A possible hypothesis, supposing that MFs have an exogenous origin, could be that they are being transported in the open ocean in a different way from the rest of the plastic waste, maybe by its composition (Erni-cassola et al., 2019). Another plausible hypothesis, assuming that the MFs have an endogenous origin in the islands, could be deduced: they are being dumped into the sea via ravines and/or via wastewater discharges (Villiers, 2018), and/or are accumulating on the beaches due to such users.

As mentioned in the Introduction, there are many investigations that corroborate this fact in different parts of the world (Prata, 2018), insisting that the quantity of MFs emitted into the marine environment is directly related to the flow of the outflow, and the most frequent colors of the MFs are blue, transparent, and black (Gago et al., 2018), as found in the present work (Fig. 3a). In the case of Gran Canaria Island, as can be seen in Table S2, many of the wastewater discharged to the sea is not authorized, does not receive any treatment or has only primary treatment, only the most important receive secondary or thirty treatment. Then, if the wastewater is contaminated with MPs, it is being discharged directly into the sea.

In this study, this second hypothesis is a priori. As seen in Fig. 5 and Table 3, Cuervitos (D) with Veneguera (F) was the smallest beach influenced by wastewater and has almost no users (Table 1). Therefore, taking into account that these beaches received the lowest average annual values of MFs (Table 2), it is possible to give greater solidity to the hypothesis that wastewaters are MF vectors content in the Gran

Canaria coasts.

In the results, the correlation between wastewater discharged and MF distribution is visible but their relation with the type of wastewater is not clear. If is taken up again, (Table 2) Del Águila (E), La Cicer (B), and La Laja (C) beaches show the maximum average concentrations of MFs.

In the case of La Laja (C), the result was expected due to this beach is characterized to show the largest *Ftot* (Fig. 5, PC2), in contrast with Cuervitos (D) and Veneguera (F) beaches. Nonetheless, is not possible to attribute this among of fibre contamination to any type of wastewater.

Nevertheless, in the case of Del Águila (E) and La Cicer (B), the influence of residual urban and brine discharges could be related to the high accumulation of MFs. Part of this hypothesis would be well-posed, as stated in the bibliography, that urban wastewater contains large amounts of MFs due to the clothes washing (Browne et al., 2011). Then, in the case of La Cicer (B), the great accumulation of MFs with respect to the rest of beaches could be explained with the wastewater discharges. However, in the case of Del Águila (E), the amount of MFs concentration should be in relation with brine wastewater discharged. To date, it is not clear if this type of wastewater has MF concentrations; therefore, a direct investigation of such wastewater that corroborates the proposed hypothesis is necessary.

The fact that both beaches have the highest rates of use should also be considered (Table 1), since these activities could also contribute to MFs pollution. Additionally, the degree of such influence would have to be studied in a more direct way.

Given the lack of periodic sampling to complement the data found, in sediments, in marine water near the shore, and in the outflow of wastewater discharges, it has not been possible to generate a statistical model that verifies that the distribution of MFs on the island is mainly due to the influence of wastewater discharges. However, through this study, it can be seen that there are some factors affecting the accumulation pattern and that these are different from the patterns of large MPs and MEPs.

5. Conclusions

Maximum mean concentrations of 4900.0 ± 3824.8 item/m^2 were found for microfibres, 607.3 ± 429.2 items/m^2 and 7.5 ± 6.3 g/m^2 for microplastics 1–5 mm, 97.0 ± 64.3 items/m^2 and 13.1 ± 9.6 g/m^2 for mesoplastics.

The main types of large size fraction (microplastics 1–5 mm and mesoplastics 5–25 mm) found were plastic fragments and the predominant colors were white and grey-ish. Moreover, the distribution of these fractions was influenced by the predominant directions of the wind, waves, and current. There were higher concentrations on the north/northeast slopes and the exogenous origin of plastic residues (1–25 mm) was confirmed due to the presence of high amount of resin pellets. There is also evidence of endogenous contamination for this fraction in the presence of ear sticks and other plastic debris.

In the smaller fraction, only microfibres were found, presenting a distribution pattern different than the other two fractions (1–25 mm), suggesting a possible endogenous contamination in function of the type and amount of wastewater discharged.

Future studies are needed to determine if the source of microfibres is local and if it is related to wastewater discharges.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2020.110967.

Funding sources

This work was partially funded by MICROTROFIC (ULPGC2015-04) awarded to A.H. and IMPLAMAC project (MAC2/1.1a/265) granted to M.G. and A.H. The support for A.H. was by a postdoctoral fellowship granted by Universidad de Las Palmas de Gran Canaria (ULPGC-2014).

CRediT authorship contribution statement

Jorge Rapp: Conceptualization, Methodology, Software, Investigation, Writing - original draft. **Alicia Herrera:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Ico Martinez:** Conceptualization, Methodology, Writing - review & editing. **Eugenio Raymond:** Investigation. **Ángelo Santana:** Formal analysis, Data curation. **May Gómez:** Validation, Writing - review & editing, Funding acquisition.

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.

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