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Arenas Blancas (El Hierro island), a new hotspot of plastic debris in the Canary Islands (Spain)

Cintia Hernández-Sánchez [a,b,*], Javier González-Sálamo [b,c], Francisco J. Díaz-Peña [d], Eugenio Fraile-Nuez [e], Javier Hernández-Borges [b,c,*]

[a] *Departamento de Obstetricia y Ginecología, Pediatría, Medicina Preventiva y Salud Pública, Toxicología, Medicina Forense y Legal y Parasitología, Área de Medicina Preventiva y Salud Pública, Escuela Politécnica Superior de Ingeniería, Sección de Náutica, Máquinas y Radioelectrónica Naval, Universidad de La Laguna (ULL), Vía Auxiliar Paso Alto, 2, 38001 Santa Cruz de Tenerife, Spain*

[b] *Instituto Universitario de Enfermedades Tropicales y Salud Pública de Canarias, Universidad de La Laguna (ULL). Avda. Astrofísico Fco. Sánchez, s/n°, 38206 San Cristóbal de La Laguna, Spain*

[c] *Departamento de Química, Unidad Departamental de Química Analítica, Facultad de Ciencias, Universidad de La Laguna (ULL), Avda. Astrofísico Fco. Sánchez, s/n, 38206 San Cristóbal de La Laguna, Spain*

[d] *Departamento de Biología Animal, Edafología y Geología. Facultad de Ciencias, Universidad de La Laguna (ULL). Avda. Astrofísico Fco. Sánchez, s/n, 38206 San Cristóbal de La Laguna, Spain*

[e] *Centro Oceanográfico de Canarias, Instituto Español de Oceanografía (IEO), Consejo Superior de Investigaciones Científicas (CSIC), Calle Farola del Mar, 22, 38180 Santa Cruz de Tenerife, Spain*

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ABSTRACT

The present work has studied the incidence and type of micro (1–5 mm), meso (5–25 mm) and macroplastics (>25 mm) that have reached Arenas Blancas beach, located in the north coast of El Hierro island, in the Canary Islands (Spain), from October 2019 to May 2020 (13 sampling dates with 3 sampling points each). Taking into consideration the three studied plastic debris fractions (macro, meso and microplastics), a total of 9206 items were found, which had a total weight of 1169.7 g and a concentration of 891.3 ± 91.5 items/m^2 (118.3 ± 17.8 g/m^2 and 2.3 ± 0.4 g/L). Regarding their colour, most of them were transparent/white/clear, especially in the microplastic fraction in which they accounted for a 68% of the total. Attenuated Total Reflectance Fourier Transform Infrared spectroscopy of meso and microplastic fractions indicated that most of the particles were either polypropylene and polyethylene followed by polystyrene in a much lower amount. In general, the total amount of plastic debris that arrives to the beach by the persistent oceanic current pattern linked to the easternmost branch of the North Atlantic Subtropical Gyre is comparable to those of the most contaminated beaches of the Canary Islands archipelago, suggesting that a new hotspot of plastic debris arrival has been found.

1. Introduction

Nowadays, it is clear that the world is currently facing important environmental problems, being one of them the high plastic contamination of every environmental compartment (Wang et al., 2021). Scientists all over the globe are currently providing more and more evidence of their widespread presence and effects, as well as facing important challenges regarding their detection and quantification, which is not an easy task, especially when they have an extremely small size, i.e. low size microplastics and nanoplastics (Hernández-Sánchez et al., 2020; Vighi et al., 2021). In this context, monitorization programs clearly provide relevant data that will surely contribute to solve the "puzzle" of plastic contamination, as well as to allow to take actions against it.

Since October 2019, the Interreg-MAC project IMPLAMAC, "Evaluation of the impact of microplastics and emerging contaminants in the coasts of the Macaronesian region", is periodically monitoring the

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* Correspondence to: Cintia Hernández-Sánchez; Departamento de Obstetricia y Ginecología, Pediatría, Medicina Preventiva y Salud Pública, Toxicología, Medicina Forense y Legal y Parasitología, Área de Medicina Preventiva y Salud Pública, Escuela Politécnica Superior de Ingeniería, Sección de Náutica, Máquinas y Radioelectrónica Naval, Universidad de La Laguna (ULL), Vía Auxiliar Paso Alto, 2, 38001 Santa Cruz de Tenerife, Spain, Javier Hernández-Borges; Departamento de Química, Unidad Departamental de Química Analítica, Facultad de Ciencias, Universidad de La Laguna (ULL), Avda. Astrofísico Fco. Sánchez, s/n, 38206 San Cristóbal de La Laguna, Spain.

E-mail addresses: chernans@ull.edu.es (C. Hernández-Sánchez), jhborges@ull.edu.es (J. Hernández-Borges).

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arrival of microplastics at beaches of the Canary Islands, Madeira, Azores and Cape Verde archipelagos (IMPLAMAC, 2021) in an effort for understanding, from a global point of view, the arrival of microplastics to this particular place of the globe, which has been documented to be a sink of these contaminants from the open North Atlantic Ocean caused by the southward flow Canary Current (Álvarez-Hernández et al., 2019; Baztan et al., 2014; Edo et al., 2019; González-Hernández et al., 2020; Herrera et al., 2018; Rapp et al., 2020; Reinold et al., 2020). Among the different objectives stablished in this project, there can be highlighted the finding of hotspots of microplastic arrival (places in which higher amounts of microplastics are accumulated), in order to specifically study such issue in greater depth, in particular, their fate and transport dynamics. The identification of such accumulation zones is also of relevance in order to assist future clean-up operations or targeted mitigation strategies (Rochman, 2016).

Concerning the Canary Islands archipelago, up to now, the presence of microplastics (in some cases mesoplastics were also simultaneously analysed) has been documented in beaches of the islands of Lanzarote (Baztan et al., 2014; Herrera et al., 2018), La Graciosa (Baztan et al., 2014; Edo et al., 2019; Herrera et al., 2018), Fuerteventura (Baztan et al., 2014), Gran Canaria (Herrera et al., 2018; Rapp et al., 2020) and Tenerife (Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Reinold et al., 2020), while no studies have reported their presence in the most occidental islands of La Palma, La Gomera or El Hierro.

Although there is not a clear definition of what a hotspot of plastic pollution is (especially that of microplastic), several beaches of the Canary Islands have been catalogued as such: Playa del Ámbar (locally known as Playa Lambra) in La Graciosa (Baztan et al., 2014; Edo et al., 2019; Herrera et al., 2018), Playa de Famara in Lanzarote (Baztan et al., 2014; Herrera et al., 2018) and Playa Grande in Tenerife (Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Reinold et al., 2020), which are beaches with a north or north-east orientation with visual evidences of contamination at any time of the year and reported values of more than 100 g/m^2 of plastics in certain periods of the year. In previous studies carried out in the region, it has been suggested in a good number of occasions that beaches with such orientation (north or north-east) are prone to receive a high arrival of microplastics.

El Hierro, is the southern and westernmost island of the Canary Islands. Having a population of 11147 inhabitants during 2020 (ISTAC, 2021) and with the absence of large industries, it is the first of the islands to cover more than half of its energetical needs through renewable energy (Garcia Latorre et al., 2019). However, all these relevant issues do not make the island immune to the microplastic problem.

Arenas Blancas beach is located in the north of El Hierro island, and it has an east orientation, being a good candidate for the monitorization of the microplastics arrival as consequence of the Canary Current, the easternmost branch of the North Atlantic Subtropical Gyre (Machín et al., 2006, 2010; Fraile-Nuez and Hernández-Guerra, 2006; Fraile-Nuez et al., 2010) as previous studies in other areas of the Canary archipelago have suggested (Álvarez-Hernández et al., 2019; Baztan et al., 2014; Edo et al., 2019; González-Hernández et al., 2020; Herrera et al., 2018; Rapp et al., 2020; Reinold et al., 2020). Within the IMPLAMAC project, the arrival of micro (1–5 mm), meso (5–25 mm) and macroplastics (>5 mm) at that beach has been monitored since October 2019 until May 2020. This article is aimed at studying the spatial and temporal distribution of plastic debris at Arenas Blancas beach, including their classification by shapes and colours, as well as at identifying the composition of such contaminants. To the best of our knowledge, this is the first article reporting the presence of plastic debris in El Hierro island. The data reported in this particular study will also allow the possible identification of other hotspots of plastic debris in the Macaronesian region, which is of particular importance in order to take further mitigation and clean-up actions as well as to understand with more depth plastics dynamics in the region.

2. Materials and methods

2.1. Study area and field work

Arenas Blancas beach was sampled approximately every 15 days from 30th October 2019 to 15th May 2020, except in the period from 13th March to 15th April 2020, in which, due to the lockdown established in Spain caused by the COVID-19 pandemic (which started on 15th March 2020), only four samplings could be developed. The beach is 13.8 km from the nearest town (La Frontera) with only 4184 inhabitants (ISTAC, 2021). Table 1 shows the characteristics of the beach as well as the sampling dates while Fig. 1 shows an image of the location of El Hierro island in the Canary Islands archipelago and of Arenas Blancas beach.

Sampling was developed in three different points of the beach at the highest tide line of that day and with a separation of approximately 10 m between each point, following the indications of the Guidance of Marine Litter in European Seas of the European Commission (European Commission, 2013) by depositing on the sand a frame of 50 × 50 cm to delimitate the sampled sand fraction and by using a stainless-steel vessel to collect the sand down to 5 cm deep. To clean each sample, seawater was added, ensuring that no plastic particles with a size greater than 1 mm were present. Then the supernatant was filtered through a 1 mm mesh and transferred to a glass jar and transported to the laboratory for further analysis. Microplastics lower than 1 mm size were not considered since IMPLAMAC project is currently focused on bigger microplastics, including meso and macroplastics.

2.2. Separation of micro, meso and macroplastics

Once at the laboratory, the content of the glass jars was sieved using certified 1- and 5-mm stainless-steel circular sieves of 20 cm of diameter (VWR® International). Micro (1–5 mm), meso (5–25 mm) and macroplastic (>25 mm) fractions were introduced in a NaCl saturated solution (approximate density of the solution 1.2 kg/L). The floating material was transferred to a Büchner funnel containing a filter paper and washed with deionized water and air dried. Afterwards, non-plastic materials easily identifiable to the naked eye such as pieces of algae, tar, wood, etc. were removed (in the case of tar it was also recorded) and the three groups of plastics were separately weighted in an analytical balance (Sartorius Entris 224I-1S analytical balance with a maximum weighting capacity of 220 g and 0.1 mg of resolution). Micro, meso and macroplastics were then counted and separated by colours and shapes. For microplastics studies, shape was determined by visualizing the particles on a Nexus Zoom binocular stereomicroscope - 0.65×-5.5× - from Euromex equipped with a M1400 Plus Camera from Levenhuk, using LevenhukLite software for camera control and image treatment. An Elix Essential water purification system from Millipore (Burlington, MA) was used to purify regular tap water, which was then deionized with a Milli-Q A10 gradient system also from Millipore and used for the preparation of the NaCl saturated solution.

Table 1
Characteristics of the Arenas Blancas beach and sampling days.

Beach name	Arenas Blancas
Municipality	La Frontera (El Hierro)
Sampling days	30/10/2019; 16/11/2019; 2/12/2019; 17/12/2019: 2/01/2020; 15/01/2020; 31/01/2020; 17/02/2020; 2/03/2020; 13/03/2020; 15/04/2020; 30/04/2020; 15/05/2020
Coordinates	Lat: 27°46′00.66″N lon:18°07′18.38″O x: 192,314.51 y:3,075,283.06
Total length	154 m
Touristic impact	Very low
Orientation	East
Sand type	Fine (white)
Cleaning	Sporadic days (developed by volunteers)
Number of sampling points per day	3

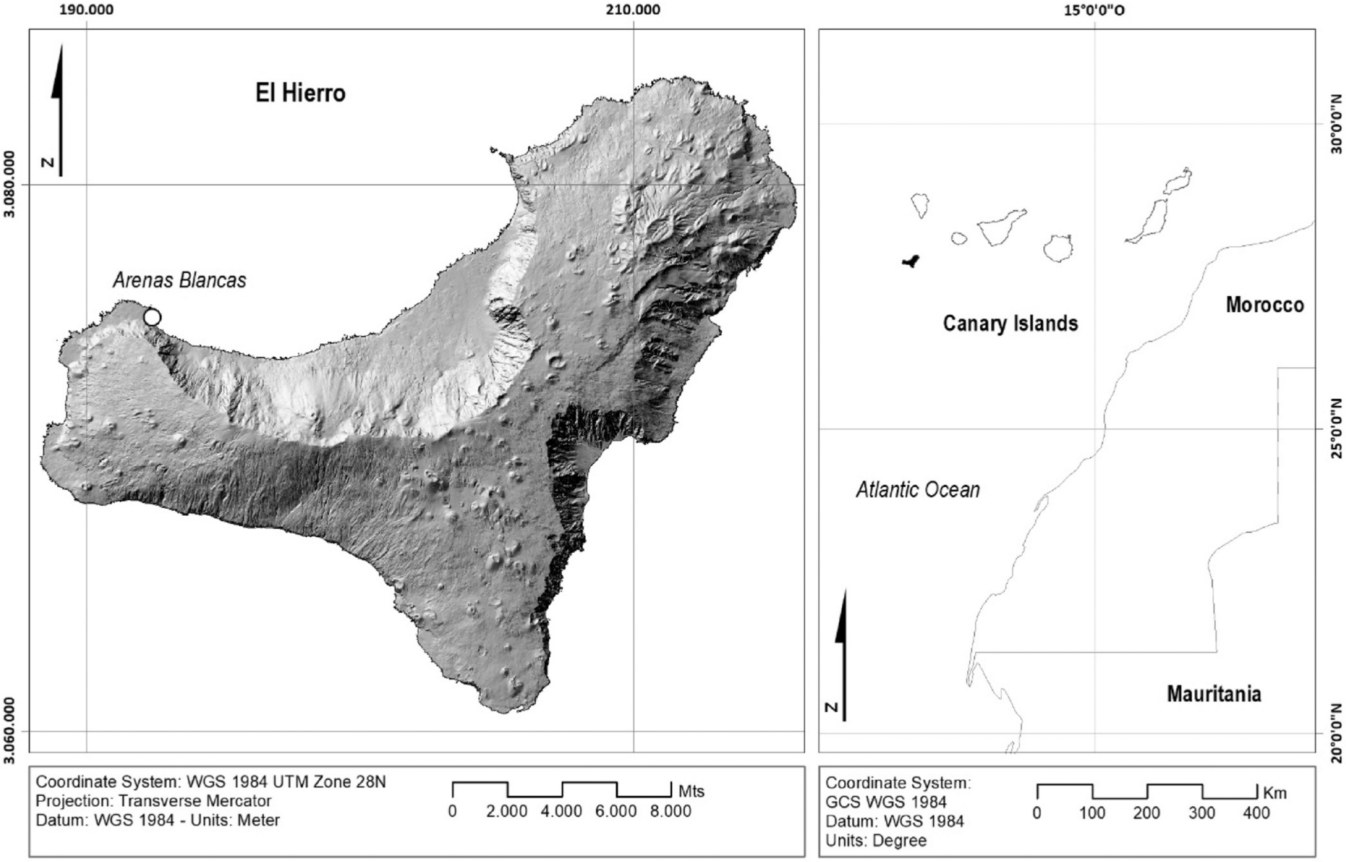

Fig. 1. Location of Arenas Blancas beach in El Hierro island (Canary Islands, Spain).

2.3. Infrared analysis

For infrared (IR) measurements, a Fourier Transform IR (FTIR) spectrometer Agilent Cary 630 equipped with an Attenuated Total Reflectance (ATR) accessory was used (Agilent Technologies, California, USA), with a one-bounce (nominal angle 45 degrees) diamond crystal, a high-throughput Michelson interferometer with fixed and moving flat mirrors, a low-powered solid stated laser, a wire-wound element infrared source, a KBr beamsplitter, and a 1.3 mm diameter thermoelectrically cooled deuterium triglycine sulphate (dTGS) detector. FTIR spectra were collected between 4500 and 500 cm^{-1} at a resolution of 8 cm^{-1} with 32 scans per spectrum (Happ-Genzel apodization function was applied). Agilent MicroLab PC software was used to acquire spectra, while Agilent Resolutions Pro software was used for spectra identification using polymers spectral libraries. A derivative algorithm was used for spectra identification and the minimum matching for positive identification was set at hit quality index (HQI) values ≤ 0.60 over 2.00, which corresponds to a 70% of positive identification. Matches between 60 and 70% were individually examined and only identified when a clear evidence of peaks corresponding to known synthetic polymers were found. Spectra with HQI higher than 0.80 were directly classified as unidentified. Such criteria was set following the indications of the Guidance of Marine Litter in European Seas of the European Commission (European Commission, 2013).

2.4. Statistical analysis

Statistical methods were implemented using Statistical Package for the Social Sciences (SPSS, Version 25.0). The level of significance for all tests was set to $p < 0.05$. To detect differences in plastic debris (items/m^2 or g/m^2) among all sampling dates, ANOVA and a post hoc Tukey's test were used. A Kuskal–Wallis test and a non-parametric Tukey-type multiple comparisons test were used when parameters did not conform to a normal distribution (Kolmogorov Smirnov test) and homogeneity of variance (Levene test).

2.5. Ocean current dataset

Daily surface ocean current data were extracted from the Iberian Biscay Irish (IBI) Ocean Analysis and Forecast System from Copernicus in Netcdf files from June 2019 to June 2020. Surface current maps were elaborated under Matlab 2021 scripts with the use of m_map v1.4m package toolbox and a coastline database of ¼ degree resolution.

The IBI Ocean Analysis and Forecast System from Copernicus is based on an operational suite system that daily run by Nologin company (Spain), in coordination with Puertos del Estado (Spain) with the support, in terms of supercomputing resources, of CESGA Supercomputing Center of Galicia (Spain). The model code was developed by Mercator Ocean – Copernicus (https://marine.copernicus.eu) as a physical product (IBI_AnalysisForecast_phy_005_001). Its objective is to produce a near-real-time short-term (5 days) forecast of currents and other oceanographic variables, such as temperature, salinity, and sea level, as well as to obtain a better understanding of the ocean dynamic in the IBI Atlantic waters (Sotillo et al., 2015). The system is based on a (eddy-resolving) NEMO-v3.6 model application driven by high frequency meteorological and oceanographic forcing that run at 1/36° horizontal resolution (~3 km). The model produces results at 50 z levels, which are unevenly spaced vertical levels covering the whole column (from 5800-m depth to the surface). The thickness of the layers is around 1 m resolution near the surface, and up to 400 m at the bottom of the ocean.

3. Results and discussion

3.1. Sampling, macro/meso/microplastics separation and quantification

As previously indicated, a total of thirteen samplings were carried out in Arenas Blancas (El Hierro) during October 2019–May 2020 nearly every 15 days, except for the period from 13th March to 15th April 2020 as consequence of the lockdown in Spain caused by COVID-19, in which only four samplings could be developed. The beach, which is located on the north of El Hierro, has an east orientation and, therefore, as previous works carried out in other islands of the archipelago have reported (Baztan et al., 2014; Edo et al., 2019; Herrera et al., 2018; Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Reinold et al., 2020) its location and orientation (in combination with the prevalent winds and currents of the archipelago) might make it a good candidate for high plastic debris arrival. Besides, a previous on-site analysis of other beaches of the island, including questionaries carried out with local people, leaded our research within the IMPLAMAC project to monitor this beach, in particular, looking for macro, meso and microplastics, in this last case, only those with the highest dimensions (1–5 mm).

Table 2 shows the amounts of micro, meso and macroplastics sampled during the study period, expressed in different units to facilitate data comparison, while Fig. 2 shows the temporal evolution in the concentration of the three fractions expressed as items/m^2 and g/m^2. The data of the table include average, maximum and minimum values as well as the standard error of the mean. Concerning microplastics (1–5 mm) an average concentration of 559.2 ± 68.2 (standard error) items/m^2 (equivalent to 14.9 ± 3.0 g/m^2 and 0.2 ± 0.0 g/L) was found, being the total number of items 6034, which had a total weight of 151.16 g. Regarding mesoplastics, the total number of items found were lower, 2822, as well as the concentration, 290.0 ± 28.7 items/m^2, however, as expected from bigger particles, the total weight was higher (603.49 g) and, as a result, the concentration expressed as g/m^2 and g/L was also higher (61.3 ± 7.5 g/m^2 and 1.2 ± 0.2 g/L). For macroplastics, the total weight was 415.09 g (concentration of 42.0 ± 11.1 g/m^2 and 0.8 ± 0.2 g/L) being the total number of items found 350 with a concentration of 42.1 ± 7.4 items/m^2. Taking into account the three fractions (macro, meso and microplastics), 9206 items were found, which had a total weight of 1169.74 g (118.3 ± 17.8 g/m^2 and 2.3 ± 0.4 g/L) and a concentration of 891.3 ± 91.5 items/m^2. Relationship between number of items and mass for the three sampled fractions is shown in Fig. S1 of the Supplementary material.

As can be seen in Fig. 2, the highest number of items and grams per area unit were found on December 2, 2019, March 2 and May 15, 2020 for microplastics, on December 2, 2019, January 15 and March 2, 2020 for mesoplastics and January 31, February 17 and May 15, 2020 for macroplastics. Significant differences between micro and mesoplastic fractions collected on March 13, 2020 and the rest of samplings were observed, being concentration for that date extremely low (Table 2).

Although the available data do not correspond to a full year monitoring, we also developed a comparison between seasons (see Fig. S2 of the Supplementary material), which revealed that there were not significant differences between seasons. Since summer data was not available, as well as a longer monitoring period, no conclusions could be drawn. In fact, in the only study that has been published in the Canary Islands regarding an annual study of micro and mesoplastics (beaches of Famara in Lanzarote, Lambra in La Graciosa and Cuervitos in Gran Canaria) seasonal variation between the beaches was also different (Herrera et al., 2018).

Since the abundance of beach litter is very influenced by oceanic currents, prevailing winds and the exposure of the beach, in an attempt to relate the temporal variation of the plastic debris arrival to Arenas Blancas beach with the prevalent currents during the sampling period, the high spatial-temporal resolution surface velocity data were analysed for the entire Canary Archipelago. Fig. 3a shows the surface annual mean velocity map representation of the predominant Canary Current through the Canary Islands. Although the mean velocity over a whole year and area is around 7.5 ± 1.6 cm/s, maximum values of up to 0.25 m/s can be found in the area mostly linked to inter-channel currents, upwelling filaments and mesoscale activity. The north part of El Hierro

Table 2
Amount of micro (1–5 mm), meso (5–25 mm) and macroplastics (>25 mm) found in Arenas Blancas beach from October 2019 to May 2020 (13 sampling days).

Plastic type	Items, weight and concentrations	Amount	Maximum (per sampling day and date)	Minimum (per sampling day and date)
Macroplastics (>25 mm)	Total number of items	350[*]	56 (17/02/2020)	12 (13/03/2020)
	Total weight of macroplastics (g)[**]	415.09[*]	122.60 (15/01/2020)	3.95 (13/03/2020)
	Items/m^2	42.1 ± 7.4[***]	126.7 ± 32.1 (17/02/2019)	16.0 ± 14.0 (13/03/2020)
	g/m^2	42.0 ± 11.1[***]	163.5 ± 82.4 (15/01/2020)	5.3 ± 4.5 (13/03/2020)
	g/L	0.8 ± 0.2[***]	3.3 ± 1.6 (15/01/2020)	0.1 ± 0.1 (13/03/2020)
Mesoplastics (5–25 mm)	Total number of items	2822[*]	355 (02/03/2020)	8 (13/03/2020)
	Total weight of mesoplastics (g)[**]	603.49[*]	85.59 (15/01/2020)	2.19 (13/03/2020)
	Items/m^2	290.0 ± 28.7[***]	473.3 ± 289.4 (02/03/2020)	10.7 ± 7.1 (13/03/2020)
	g/m^2	61.3 ± 7.5[***]	114.1 ± 22.5 (15/01/2020)	2.9 ± 2.6 (13/03/2020)
	g/L	1.2 ± 0.2[***]	2.3 ± 0.4 (15/01/2020)	0.1 ± 0.0 (13/03/2020)
Microplastics (1–5 mm)	Total number of items	6034[*]	1420 (15/05/2020)	20 (13/03/2020)
	Total weight of microplastics (g)[**]	151.16[*]	46.49 (15/05/2020)	0.46 (13/03/2020)
	Items/m^2	559.2 ± 68.2[***]	922.0 ± 26.0 (16/11/2019)	26.7 ± 15.0 (13/03/2020)
	g/m^2	14.9 ± 3.0[***]	46.5 ± 11.9 (15/05/2020)	0.6 ± 0.3 (13/03/2020)
	g/L	0.2 ± 0.0[***]	0.4 ± 0.3 (15/05/2020)	0.0 ± 0.0 (13/03/2020)
Total plastics	Total number of items	9206[*]	1738 (15/05/2020)	40 (13/03/2020)
	Total weight of plastics (g)[**]	1169.74[*]	215.15 (15/01/2020)	6.48 (13/03/2020)
	Items/m^2	891.3 ± 91.5[***]	1408.0 ± 247.5 (02/03/2020)	53.3 ± 4.7 (13/03/2020)
	g/m^2	118.3 ± 17.8[***]	286.9 ± 45.5 (15/01/2020)	8.8 ± 1.3 (13/03/2020)
	g/L	2.3 ± 0.4[***]	5.7 ± 0.9 (15/01/2020)	0.2 ± 0.0 (13/03/2020)

[*] Total values.

[**] Plastics were weighted using an analytical balance but their weight was adjusted to two decimals.

[***] Average values ± the standard error.

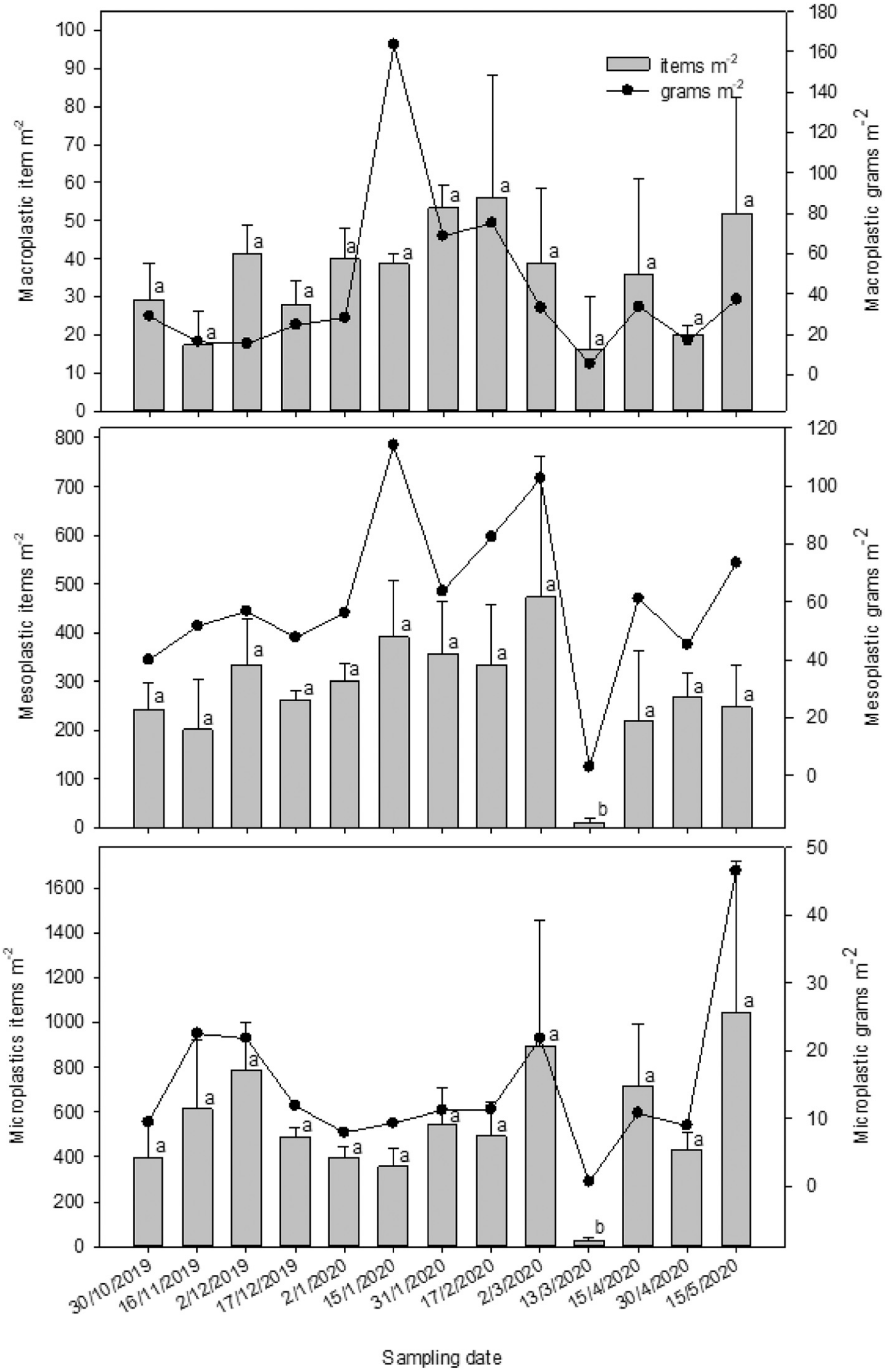

Fig. 2. Temporal evolution in the concentration of micro, meso and macroplastics expressed as items/m^2 and g/m^2 in the sampling period (October 2019–May 2020). Different letters indicate significant differences ($p < 0.05$) among sampling dates.

island is characterized by a mid-intense southeast current between 0.15 and 0.20 m/s. This current seems to be connected by other strong local currents/re-circulations as south-Gran Canaria, south-Tenerife and west-Tenerife that may fed the north of El Hierro island with a significative higher floating litter than if the current directly proceeded from open waters. In that sense and knowing that Arenas Blancas beach is located in the north part of El Hierro island with an open access to the north-northeast waters, we evaluated the predominant annual intensity and direction of the current in a point located 4.4 km north-east of the beach (Fig. 3a, red dot). Fig. 3b shows the annual mean intensity and direction rose diagram at this location, which presents a stable and strong south-west pattern in the direction of the current, directly to the orientation of Arenas Blancas beach.

In the same way, Figs. S3 and S4 of the Supplementary material show the seasonal current circulation scheme for the Canary Island and the seasonal mean intensity and direction rose diagrams, respectively. As it can be seen in the annual pattern (Fig. 3b), the seasonal main current direction at the north-east location of Arenas Blancas beach (Fig. S4) is predominant to the south-west in every single season, but especially during summer and winter.

Furthermore, in order to try to relate the obtained data with the wind direction and speed as well as with wave direction and height, azimuth

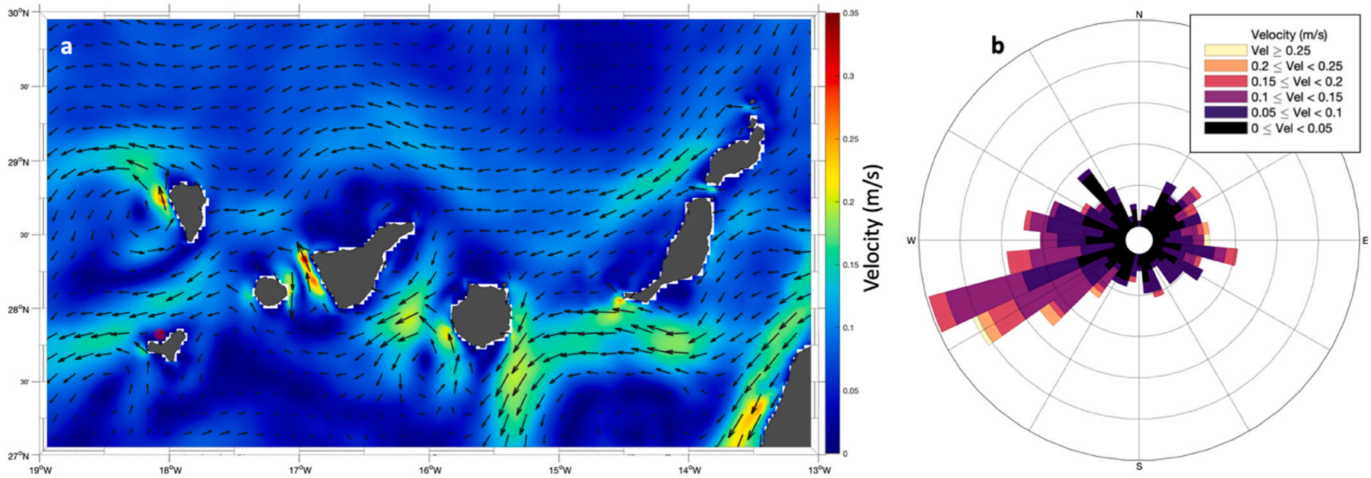

Fig. 3. Annual Current intensity for the Canary Archipelago. (a) Annual surface quiver velocity map representation in (m/s) from the data extracted from IBI-Copernicus for the Canary Island region. (b) Annual velocity intensity and current direction distribution rose diagrams for a pixel located 4.4 km north-east from Arenas Blancas (El Hierro Island).

plots of the variation of such factors during autumn 2019, winter 2019–2020 and spring 2020, which are shown in Figs. S5 and S6 of the Supplementary material, were examined. Such information was obtained from Puertos del Estado (Spanish Ministry of Transport, Mobility and Urban Agenda) (Ministerio de Transporte, 2021). During the sampling period, wind direction had an overall predominant east-northeast or northeast direction (both between 20 and 40% of the period) with a speed higher than 8 m/s around a 25% of the time. On the contrary,

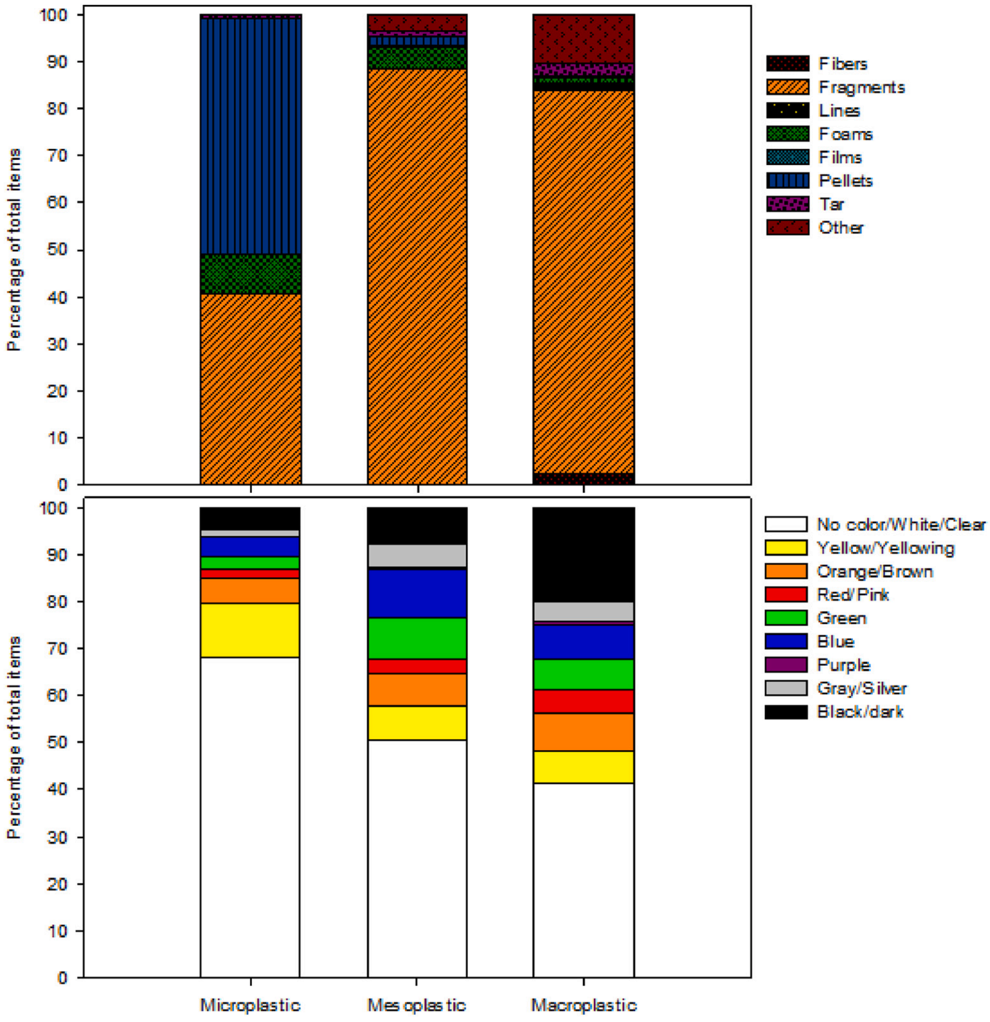

Fig. 4. Total shape and colour distribution of the micro, meso and macroplastics found in this study.

waves had a predominant north and north-northwest direction with a height higher than 2–3 m (both between 30 and 45% of the period). These facts, together with the east orientation of the beach, may result in a good combination of factors for the constant arrival of plastic debris that are close to the island, though other factors, including oceanic mesoscale processes should also be considered.

A more careful look at the wind speed and patterns during the period July 2019 and May 2020 showed that August, September, November, February, and March are the months with the highest mean wind speeds (higher than 7.25 m/s during 2019 and the first four months of 2020). As can be seen in Fig. 2, samplings carried out on December 2, 2019, March 2, 2020 and April 15, 2020 showed the highest values of microplastics items/m^2, which might be related with such issue, though on May 15, 2020 the highest number of items/m^2 and g/m^2 of microplastics were also observed but the previous average month wind speed was not as high as the rest. Regarding meso and macroplastics fractions, no pattern can be observed.

Concerning the extremely low number and amount of meso and microplastics found on March 13, we do not have a clear explanation for such reduction in the concentration of both of them, which also happened just before the maximum arrival of them on March 2. A possible explanation might be a non-registered cleaning of the beach, which is not frequent at all.

3.2. Microplastics morphology and colour

Once all the fractions were weighted, they were classified as fibres, fragments, lines, foams, films and pellets; if other shapes were found they were also separated. Fig. 4 shows the total shape and colour distribution of the micro, meso and macroplastics found in this study, in which the tar fraction can also be seen, since it is also of relevance and has still been frequently found in the region in the last years, as previous studies have shown (Álvarez-Hernández et al., 2019; Baztan et al., 2014; Edo et al., 2019; González-Hernández et al., 2020; Herrera et al., 2018; Rapp et al., 2020; Reinold et al., 2020). As can be seen in the figure, in the meso and macroplastic fractions, fragments were mainly found. In the particular case of microplastics, 49.9% were pellets and 40.7% fragments, while 8.4% were foams, 0.1% films and 0.1% lines (0.1% belonged to a different shape, i.e. burnt plastic). Among all items, approximately 0.8% were tar. Such high number of pellets, which were of different colours (yellowish, transparent, black, green, etc.) -see Fig. S7 of the Supplementary material as an example- is quite surprising since no plastic industry is present in the island, though they do exist in both Tenerife and Gran Canaria islands in a very reduced number. However, in those previous works developed in such islands, the amount of pellets were always below 14% (Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Rapp et al., 2020; Reinold et al., 2020). Despite the fact that no plastic industries can be found in the island, we also checked the proximity of wastewater discharge point finding that only four of them existed and that only one was located on the north of the island (see Fig. S8) which, judging from the currents at the north of the island, could bring to the beach buoyant debris (if they were existent). Even though, as previously indicated, plastic weathering was really high, which clearly indicated that they came from the North Atlantic.

Most of the pellets had a yellowish colour, which clearly suggest their high persistence in the sea and their offshore origin. Regarding mesoplastics, such classification may still be maintained. In this case, 88.0% were fragments, 4.7% foams, 1.8% pellets, 0.4% were films, 0.3% fibres and 0.1% lines, while 3.4% had a different form (also burnt plastic). Regarding pellets of such higher size, it was not clear whether they are used as raw materials like microplastic pellets or not. Among the 5–25 mm fraction, 1.2% was tar. Finally, 84.3% of macroplastics were fragments, 2.2% fibres, 1.2% lines, 1.0% foams and 0.2% films. A 2.4% was tar, while an 8.7% had a different shape: some items were easily recognizable, e.g. toys, fishing buoys, while others were burnt plastic. If pellets were not considered, similar percentages of fragments (81.1%) can be found in the three fractions, followed by foams (16.7%), which might suggest a relation with the fragmentation of bigger plastics.

Regarding the colours, they were classified as transparent/white/clear, yellow/yellowish, orange/brown, red/pink, green, blue, purple, gray/silver and black/dark. As can also be seen in Fig. 4, most of them were transparent/white/clear, especially in the microplastic fraction in which they accounted for a 68% of the total. In this last case, 11.5% had a yellow/yellowish colour, while 5.6% were orange/brown, 4.6% black/dark, 4.0% blue, 2.8% green, 1.8% gray/silver, 1.6% red/pink and 0.1% purple. Concerning the mesoplastic fraction, 50.6% were transparent/white/clear, 10.5% blue, 8.6% green, 8.0% were black/dark, 7.2% had a yellow/yellowish colour, 6.7% were orange/brown, 4.8% gray/silver, 3.2% red/pink and 0.4% purple. Finally, regarding the macroplastic fraction, 35.0% were transparent/white/clear, 22.2% were orange/brown, 16.9% black/dark, 6.0% blue, 5.8% had a yellow/yellowish colour, 5.6% were green, 4.1% pink, 3.6% gray/silver and 0.7% purple. Except for the white colour, the rest of the particles did not show a clear colour abundance between fractions, though orange/brown was the second most abundant among macroplastics, blue among mesoplastics and yellow/yellowing among microplastics. As it also happened for plastics shapes, if pellets were not considered, similar percentages of particles of the same colours can be found in the three fractions, which reinforces a possible relation between them concerning the fragmentation of bigger plastics.

3.3. Micro and mesoplastics composition analysis

Once microplastics were weighted and classified according to their shapes and colours, the composition of a representative number of them was determined by ATR-FTIR spectroscopy since characterizing unknown polymers helps to clarify many of the issues surrounding marine debris. In particular, knowing the polymer type will help to elucidate the transport and fate of these particles. For this purpose, approximately, 30 particles from each sampling point (20 with a microplastic size - 1-5 mm -, 10 of them fragments and 10 pellets since they were the most abundant, and 10 with a mesoplastic size - 5-25 mm -) were randomly separated -when available- and their absorption bands were studied and matched with Agilent polymer ATR-FTIR library. A total of 1121 particles were analysed (395 mesoplastic particles, and 726 microplastics, 355 of them were fragments and 371 pellets), which represent a 12.6% of the total number of meso and microplastics particles found (14.0% of mesoplastics and 12.0% of microplastics). Though the Guidance of Marine Litter in European Seas of the European Commission indicates that formal identification of the polymer composition is not so critical for larger particles (>500 μm) and that a proportion of 5–10% of all samples <100 μm should be routinely checked, we have also considered such threshold of 10% as a reference (European Commission, 2013).

Three major IR spectral regions reflecting weathering-related changes identified in previous research (Fernández-González et al., 2021) and which correspond to hydroxyl groups (broad peaks from 3100 to 3700 cm^{-1}, centred at 3300–3400 cm^{-1}), alkenes, or carbon double bonds (1600–1680 cm^{-1}), and carbonyl groups (1690–1810 cm^{-1}, centred at 1715 cm^{-1}) were observed in some of the samples but they did not preclude the correct identification of most of them. Also following the indications of the Guidance of Marine Litter in European Seas of the European Commission, an acceptable match quality of 70% was set, while matches between 60 and 70% were individually examined. Any sample which produced spectra with a match <60% or between 60 and 70% without a clear evidence of peaks corresponding to known synthetic polymers was rejected (European Commission, 2013). Among the analysed particles, a 28.9% of mesoplastics and 30.6% of microplastics could not be identified, which clearly suggests that they had an important weathering as a result of their high permanence in the ocean. It should be indicated that we directly used the previously indicated library without including weathered plastics. However, a detailed observation of the spectra suggested that most of them might be either polypropylene (PP), polyethylene (PE) and polystyrene (PS), though since the matching criteria was <60%, they were excluded. Fig. 5 shows the distribution of the different types of polymers identified by ATR-FTIR. As can be seen, concerning mesoplastics, 41.0% corresponded to PE polymers and 30.1% to PP. Apart from those non-identified, no other type of mesoplastics were found among the ones randomly separated. Regarding microplastics fragments, 34.4% corresponded to PP, 31.3% to PE, 1.1% to PS and a 0.3% to poly(hexadecyl acrylate), while concerning microplastic pellets, 62.3% were PE and 9.4% PP. If both fragments and pellets are simultaneously considered, 47.1% are PE microplastics, 21.6% PP, 0.6% PS and 0.1% poly(hexadecyl acrylate). In general, quite similar compositions of the three fractions were observed on average (see right part of Fig. 5), except in the case of microplastics in which a higher percentage of PE was observed. In general, these data agree with the fact that both PE and PP are the polymers most produced in the world (Plastics Europe, 2020) and that, as a result of their buoyancy, they are the ones most frequently found in the marine environment.

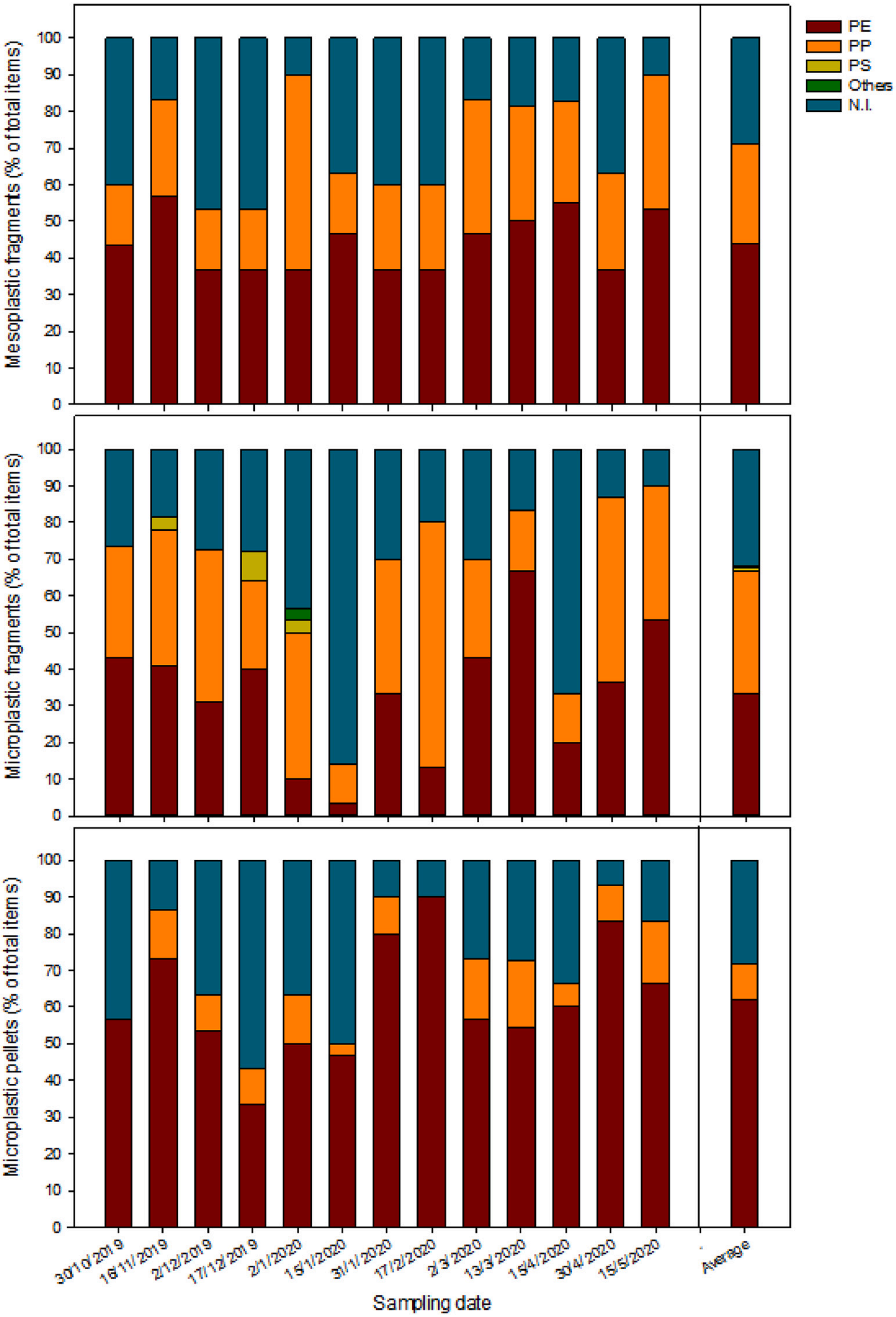

Fig. 5. Microplastic composition of the particles collected in Arenas Blancas beach (El Hierro) from October 2019 to May 2020. Analyses were carried out by FTIR (see Experimental Section for details). A total of 1121 particles were analysed (395 mesoplastic particles, and 726 microplastics, 355 of them were fragments and 371 pellets). PP: Polypropylene; PE: Polyethylene; PS: Polystyrene; N.I.: Non-identified.

3.4. Comparison with previous studies

Table 3 compiles information regarding those works in which microplastics have been analysed in the Canary Islands. Since the mesoplastic fraction has only been studied in some of them, such information has not been recorded in the table. As can be seen in the table and, as previously commented, only beaches of the islands of Lanzarote (Baztan et al., 2014; Herrera et al., 2018), La Graciosa (Baztan et al., 2014; Edo et al., 2019), Fuerteventura (Baztan et al., 2014), Gran Canaria (Herrera et al., 2018; Rapp et al., 2020) and Tenerife (Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Reinold et al., 2020) have been studied, while no studies have reported their presence in the most occidental islands, which include that of El Hierro.

Although comparison should be taken with care, since in some cases sampling was not developed following the same protocol (differences can be basically found in the sampling depth), regarding the number of microplastic items/m^2 as well as the concentration expressed as g/m^2, Arenas Blancas beach shows a similar microplastic content to that of most of the analysed beaches of the region, and it could be considered lower than those registered in the periods of higher arrival for the already settled hotspots of Famara (Lanzarote), Lambra (La Graciosa) and Playa Grande (Tenerife). However, if at least the mesoplastic fraction is considered, an average value of 76.2 g/m^2 is achieved, which increases up to 118 g/m^2 if macroplastics are also taken into consideration.

Regarding the morphology type, results are coincident with most works previously published in the region, being fragments and pellets the most abundant (Edo et al., 2019; González-Hernández et al., 2020; Rapp et al., 2020). In the case of Arenas Blancas beach, the content of pellets was really high (49.9%), the highest reported up to now in a beach of the Canary Islands, followed by that found in Famara beach (Lanzarote) in 2018 (44.3%) by Herrera et al. (Herrera et al., 2018) and in beaches of Gran Canaria (13.7%) by Rapp et al. in 2018 (Rapp et al., 2020).

The comparison between colours might be quite difficult since sometimes the colour separation criteria is not exactly the same. Even though, as can be seen in Table 3, those works in which the colours of micro and mesoplastic fractions have been analysed (Edo et al., 2019; Rapp et al., 2020; Reinold et al., 2020), white particles have mainly been found in the region (which agrees with our work), followed by a wide variety of colours, among which yellow, black, blue and green stand over the rest.

In relation to the composition of meso and microplastics fraction, only the works of Edo et al., carried out in La Graciosa island in 2019 (Edo et al., 2019), Álvarez-Hernández et al., developed in Tenerife in 2018 (Álvarez-Hernández et al., 2019), and González-Hernández et al., also carried out in Tenerife in 2019 (González-Hernández et al., 2020) analysed the microplastic composition and, therefore, only such comparison can be made. In the three cases, PE was identified as the most abundant microplastics, followed by PP and PS, though in our work the amount of non-identified polymers is much higher, probably as a result of the high degradation of such particles, which made impossible to unequivocally identify the plastic composition with at least a 60% of matching. As previously reported in such works, this data agrees with the fact that both PE and PP are the polymers most produced in the world (Plastics Europe, 2020) and that they float as a result of their low density compared with that of marine water. In none of these works, including this one, higher density polymers like PVC and PET have been found, which also suggests that they sink, or that they gain weight by the association with other materials or as a result of biofouling processes.

Regarding the analysis of plastic debris arrival in beaches of the Macaronesian region, Pieper et al. (Pieper et al., 2015) developed the first work in the Azores archipelago in which items between 2 and 30 cm were recorded in two sandy beaches of Faial (Porto Pim and Conceiçao) island during 7 months, finding total debris density values (not only plastics were examined) of 0–1940 items/m^2. Concerning the plastic fraction, it was the most abundant material but no further information regarding shapes, colours and composition was addressed.

More recently, Pham et al. (Pham et al., 2020), reported the results of the monthly monitoring of plastics of 2.1–20 mm size over a three-year period (February 2016 and October 2018) of 7 beaches of the Azores islands. Results suggested that Azorean beaches are acting as important transitory repositories for small plastic fragments floating in the North Atlantic Ocean. Ninety percent of the items were fragments, while only 5% were pellets and 4% foams. Regarding the colours, 78% of the fragments were white, which also agrees with our data, though it should be indicated that the colour was only determined for fragments and pellets. The fact that the amount of pellets was much lower than in Arenas Blancas is a clear difference that should be highlighted, though a possible explanation might be a temporal distribution since both studies were not developed in the same period. Besides, the presence of such primary microplastics in the marine environment is not homogenous, contrary to what happens to fragments, since pellets presence is mainly the result of accidental and/or unintentional spillages from transport ships during their voyages or handling of raw materials in harbours.

Pham et al. also showed that high plastic arrival in the most polluted beach, Porto Pim (Faial island), also categorized as a hotspot in that region, coincided with increased wind exposure and wave height prior to sampling. Regarding plastic loading rates, Porto Pim had a loading rate per tidal event exceeding 500 items/m^2 in 50% of the sampled months, reaching a maximum of 4782 ± 2220 items/m^2, while Praia da Areia, displayed an intermediate level of exposure (average loading rates of 245 ± 39 items/m^2). The rest of the Azorean beaches showed reduced loading rates with an average of 40 ± 9 items/m^2. If such data is compared with the ones obtained in our work, in which 559.2 ± 68.2 items/m^2 of microplastics and 290.0 ± 28.7 items/m^2 of mesoplastics were found, with a maximum of 922.0 ± 26.0 and 473.3 ± 289.4 items/m^2, respectively, it is also clear that Arenas Blancas beach also displays a similar level of exposure if only items/m^2 are considered. Since no data regarding the amount of plastic (in weight) found per square meter or the composition of the plastics were obtained, such comparison cannot be made.

In the case of Madeira and Porto Santo islands, Álvarez et al. (Álvarez et al., 2020) studied during summer 2017 micro (0.010–5 mm) and mesoplastic (5–25 mm) debris arrival in four sandy beaches of Madeira and one in Porto Santo as well as the macro litter fraction in four pebble beaches of Madeira. Among plastic macro-litter, PS was the most abundant (80% of the total items). Concerning microplastics of 1–5 mm, concentrations of approximately less than 10 items/L were found for most of the beaches except for Praia Formosa, which accounted for approximately less than 55 items/L. In the case of mesoplastics, the number of items was even much lower, which clearly indicate that they showed a much lower content than Arenas Blancas. Authors also showed that the most abundant shapes were filaments (specially for the fraction lower than 0.2 mm) and that 80% of the micro and mesoplastic items displayed white, black, gray and blue colours. However, no further data regarding specific percentages of distribution among colours or shapes nor their composition were reported for further comparison.

Concerning Cape Verde archipelago, which also belongs to the Macaronesia, to the best of our knowledge, no study has been published about plastic debris arrival in any beach, not even in its surrounding waters.

Regarding the presence of plastics in Macaronesian waters, Herrera et al. work (Herrera et al., 2020), in which microplastics floating on the surface waters of the Canary Islands, Madeira and Azores archipelagos were sampled for the first time in different periods between 2015 and 2018 (manta trawls of 200 μm mesh size were used), showed that there was a high variability in the concentrations found in the sampling areas and that the most common microplastics found in the region were fragments (which agrees with our reported data) and fibres, and that in the Canary Islands, a 49.4% of the plastics were of a 1–5 mm size and the rest between 0.2 and 1 mm (in Azores and Madeira only 17.5% and 39.4%, respectively, were 1–5 mm size). However, hardly any pellets were found in the whole study, and none in the Canary Islands, in particular, none

Table 3
Comparison of the different published works in which microplastics (1–5 mm) have been analysed in beaches of the Canary Islands (Spain). Works are shown in chronological order (from less to more recent).

Islands	Beach	Sampling	Period (number of samplings)	Items or g per m^2	Microplastics shape	Microplastic colours	Microplastic composition	Comments	Reference
La Graciosa, Lanzarote and Fuerteventura	125 beaches	50 × 50 cm 1 cm depth	January 2013 (194 samples)	(–)*	(–)	(–)	(–)		(Baztan et al., 2014)
La Graciosa, Lanzarote and Gran Canaria	Three beaches (Lambra, Famara and Las Canteras)	50 × 50 cm 1 cm depth	September 2015–September 2016 (one sampling per month)	0–12869 items/m^2 0–244.2 g/m^2	*Lambra* 52.7% fragments 11.7% pellets 35.6% tar *Famara* 43.1% fragments 44.3% pellets 12.6% tar *Las Canteras* 94.3% fragments 1.9% pellets 3.7% tar	(–)	(–)	Mesoplastics were also studied.	(Herrera et al., 2018)
La Graciosa	One beach (Lambra)	1 × 2 m 1 cm depth	September 2018 (single sampling)	(–) items/m^2 8.5–103.4 g/m^2	87% fragments 9% pellets 1.4% filaments <1% others	Black, blue, brown, green, gray, orange, pink, purple, red, translucent, white and yellow	63% PE 32% PP 3% PS	Colour distribution data were shown in a figure and not specific amount could be obtained.	(Edo et al., 2019)
Tenerife	Six beaches (Playa Grande, El Porís, Los Abriguitos, Leocadio Machado, El Socorro and San Marcos)	50 × 50 cm 5 cm depth	October–December 2018 (single sampling per beach)	2–2972 items/m^2 0–99 g/m^2	80% fragments 5% pellets 7% foams 7% fibres/lines 1% films	(–)	69% PE 18% PP 4% PS 1% nylon 8% non-identified	Supralittoral sampling.	(Álvarez-Hernández et al., 2019)
Tenerife	Eight beaches (Almaciga, Arena, Cristianos, Gaviotas, Poris, Puertito, Socorro and Tejita)	40 × 40 cm (–) cm depth	July 2016–June 2017 (every 6 weeks)	0–28218 items/m^2 0–578 g/m^2	(–)	64% white/transparent 11% yellow/orange 9% black/gray 7% blue/purple 5% green 4% red/rose/orange/brown	(–)	Microplastic studied range: 2–5 mm. Plastics with sizes between 5 and 10 mm and > 10 mm were also studied.	(Reinold et al., 2020)
Gran Canaria	Six beaches (Bocabarranco, La Cicer, La Laja, Cuervitos, Del Águila and Veneguera)	50 × 50 cm 1 cm depth	Four seasons 2018	0–1632 items/m^2 0–19.5 g/m^2	61.3% fragments 13.7% pellets 21.9% foams 0.1% fibres/lines 0.3% films 2.7% others	71.2% white/gray 10.8% black 6.2% blue 3.3% ambar 2.7% green 1.8% yellow 1.5% pink 1.4% red 0.9% orange 0.3% violet	(–)	Mesoplastics and mini microplastics 0.01–1 mm were also analysed.	(Rapp et al., 2020)
Tenerife	Playa Grande	50 × 50 cm 5 cm depth	June–July 2019 (5 samplings)	189–2571 items/m^2 0.92–36 g/m^2	83% fragments 11% pellets 4% foams 2% films	(–)	76% PE 19% PP 1% PS 4% non-identified	Moon cycle sampling. Mesoplastics were also analysed.	(González-Hernández et al., 2020)
El Hierro	Arenas Blancas		October 2019–May 2020 (13 samplings)		49.9% pellets 40.7%	68% transparent/while/clear	47.1% PE 21.6% PP	Meso and macroplastics were also analysed.	This work

(*continued on next page*)

Table 3 (*continued*)

Islands	Beach	Sampling	Period (number of samplings)	Items or g per m^2	Microplastics shape	Microplastic colours	Microplastic composition	Comments	Reference
		50 × 50 cm 5 cm depth		26.7–922 items/m^2 0.6–46.5 g/m^2	fragments 8.4% foams 0.1% films 0.1% lines 0.1% others 0.8% tar	11.5% yellow/yellowish 5.6% orange/brown 4.6% black/dark4.0% blue 2.8% green 1.8% gray/silver 1.6% red/pink 0.1% purple	0.6% PS 0.1% other 30.6% non-identified		

[*] Only general concentration data was provided in g/L. Up to 109 g/L were found. PE: Polyethylene; PP: Polypropylene; PS: Polystyrene.

near Famara (Lanzarote) or Lambra (La Graciosa), which are hotspots that have shown to have an important concentration of them in certain samplings, specially Famara (Edo et al., 2019; Herrera et al., 2018). Compared to Arenas Blancas, both beaches are located on the opposite side of the Canary Islands archipelago. The closest surface sampling point to El Hierro was Los Gigantes (west coast of Tenerife island), which also showed one of the lowest concentrations of surface microplastics of the region and the total absence of pellets. This data agrees with that recently published of Silvestrova and Stepanova (Silvestrova and Stepanova, 2021) concerning the levels of plastic contamination in the Atlantic Ocean between 35°N and 32°S from December 2019 to January 2020, which included a sampling zone above and below the Canary Islands. In their work, most of the particles found were fragments and fibres while a very low number of pellets was also found. A possible explanation might be, as previously commented, that pellets appear as a result of specific spills/discharges that do not constantly take place and, therefore, they are not as widely distributed in the sea as fragments which, on the contrary, are continuously being generated as a result of the fragmentation of bigger plastics. In any case, further research should be conducted in this sense.

In the work of Silvestrova and Stepanova previously commented (Silvestrova and Stepanova, 2021), sampling was developed using pumping systems and manta trawls. Most of the particles had a higher size (>5 mm depending on the sampling method) and were of PE as also shown by Prunier et al. (Prunier et al., 2019) who sampled micro and mesoplastics for the analysis of their metal content. Silvestrova and Stepanova (Silvestrova and Stepanova, 2021) also indicated that the distribution of potential plastic particles (according to the surface and subsurface samples visual analysis) was minimum on the equatorial zone and to the north of the Canary Islands compared to the rest sampling zones.

Regarding floating macrolitter, Chambault et al. (Chambault et al., 2018) studied its distribution and composition at the Azores archipelago and Madeira using opportunistic surveys during 2015–2017 showing that debris densities were relatively low and tended to aggregate around the Central group of the Azores and that most of the debris, which were plastics, might originate from far away land-based sources and from fishing activities. Though debris between 2.5 and 5 cm were recorded, 93% of the debris were larger than 5 cm. To the best of our knowledge, no other study of this characteristic has been developed in Canary Islands waters.

4. Conclusions

Judging from the analysis of the micro, meso and macroplastic fractions collected at Arenas Blancas beach, El Hierro island, during a nine months period, and from a comparison with previous studies of the region, it is clear that it can also be considered a new hotspot of plastic debris arrival in the Canary Islands, being the main fraction that of mesoplastics, which accounts for the highest amounts in terms of weight (average of 61.3 ± 7.5 g/m^2), though the highest number of items/m^2 corresponds to microplastics (559.2 ± 68.2 items/m^2). The composition of micro and mesoplastics (mainly PE and PP) also agrees with previous studies though an important number of them could not be identified due to plastic weathering, suggesting their long-term presence in the ocean.

Fragments were the most abundant forms in both meso and macroplastic fractions while pellets were extremely high in the microplastic fraction, though if pellets are left apart, the composition is similar in the three fractions. Such high concentration of pellets is, in fact, the highest reported up to now in any beach of the Canary Islands (up to 49.9% of the total) which is, somehow, contradictory with most of the previous works carried out in the region. Further studies should be developed to clarify this issue though it seems to be related with their punctual spillage.

Concerning the shapes and colours, transparent/white/clear fragments were the most abundant, which also agrees with previous reported data. Both distributions (shapes and colour) were similar in macro, meso and microplastics if pellets were not considered, which clearly suggest a possible relation concerning their fragmentation in the ocean.

The analysis of the archipelago currents, wind direction and speed, in particular those close to El Hierro island, clearly indicate that the high buoyant plastic debris arrival is caused by a combination of such factors with converge in a constant arrival of high amounts of plastics, in particular mesoplastics, to the beach.

CRediT authorship contribution statement

Cintia Hernández-Sánchez: Conceptualization, Methodology, Formal analysis, Resources, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Javier González-Sálamo:** Conceptualization, Methodology, Formal analysis, Resources, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Francisco J. Díaz-Peña:** Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Eugenio Fraile-Nuez:** Formal analysis, Data curation, Writing – review & editing. **Javier Hernández-Borges:** Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, 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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Appendix A. Supplementary data

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