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Review

# Microplastic and mesoplastic pollution in surface waters and beaches of the Canary Islands: A review

Andrea García-Regalado, Alicia Herrera, Rodrigo Almeda *

*EOMAR, ECOAQUA, Universidad de Las Palmas de Gran Canaria, Spain*

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ABSTRACT

The Canary Archipelago is a group of volcanic islands located in the North Atlantic Ocean with high marine biodiversity. This archipelago intercepts the Canary Current, the easternmost branch of the Azores Current in the North Atlantic Subtropical Gyre, which brings large amounts of litter from remote sources via oceanic transportation. It is, therefore, particularly vulnerable to marine plastic pollution. Here, we present a review of the available studies on mesoplastics and microplastics in the Canary Islands over the last decade to evaluate the level and distribution of plastic pollution in this archipelago. Specifically, we focused on data from beaches and surface waters to assess the pollution level among the different islands as well as between windward and leeward zones, and the main characteristics (size, type, colour, and polymer) of the plastics found in the Canary Islands. The concentrations of meso- and MPs on beaches ranged from 1.5 to 2972 items/m$^2$ with a mean of 381 ± 721 items/m$^2$. The concentration of MPs (>200 μm) in surface waters was highly variable with mean values of 998 × 10$^3$ ± 3364 × 10$^3$ items/km$^2$ and 10 ± 31 items/m$^3$. Plastic pollution in windward beaches was one order of magnitude significantly higher than in leeward beaches. The accumulation of MPs in surface waters was higher in the leeward zones of the high-elevation islands, corresponding to the Special Areas of Conservation (ZECs) and where the presence of marine litter windrows (MLW) has been reported. Microplastic fragments of polyethylene of the colour category "white/clear/uncoloured" were the most common type of plastic reported in both beaches and surface waters. More studies on the occurrence of MLW in ZEC$_S$ and plastic pollution in the water column and sediments, including small-size fractions (<200 μm), are needed to better assess the level of plastic pollution and its fate in the Canary Islands. Overall, this review confirms that the Canary Archipelago is a hotspot of oceanic plastic pollution, with concentrations of MPs in surface waters in the highest range reported for oceanic islands and one of the highest recorded mean concentrations of beached meso- and microplastics in the world.

## 1. Introduction

Plastics have become one of the most heavily utilised materials in our daily lives. The term "plastic" refers to the property of plasticity and includes different types of synthetic organic polymers mostly derived from petroleum. The worldwide production of plastics has continually increased in the last 70 years, reaching 400.3 million tonnes in 2022 (Plastics Europe, 2023). Due to their high abundance and low biodegradability, and coupled with inappropriate waste treatment and other factors, plastics are polluting all environmental compartments globally, particularly the oceans (Carpenter and Smith, 1972; Eriksen et al., 2014; Barceló and Picó, 2019). The entry of plastics into the ocean occurs through different sources, including rivers, wastewater, run-off events, maritime transportation, and atmospheric depositions (Bergmann et al., 2015; Liu et al., 2019; van Sebille et al., 2020; Turner et al., 2021; Werbowski et al., 2021; Sewwandi et al., 2022). It is estimated that up to 12.7 million metric tons of plastic waste enter the ocean every year (Jambeck et al., 2015) with this amount projected to triple by 2040 (UNEP, 2021). Therefore, the accumulation and potential impacts of plastic pollution on marine ecosystems is a major environmental issue.

The Canary Islands archipelago is located to the northwest of the African continent, about a hundred kilometers from its closest point (Fig. 1). This archipelago is exposed to the "Canary Current", the easternmost branch of the Azores Current. The Azores Current originates from the southern branch of the Gulf Stream, and it is the main recirculation current in the North Atlantic Subtropical Gyre, directed by the trade winds and limited by the African coast (Machín et al., 2006) (Fig. 2). The Canary Current brings large amounts of plastic debris from

* Corresponding author.
*E-mail address:* rodrigo.almeda@ulpgc.es (R. Almeda).

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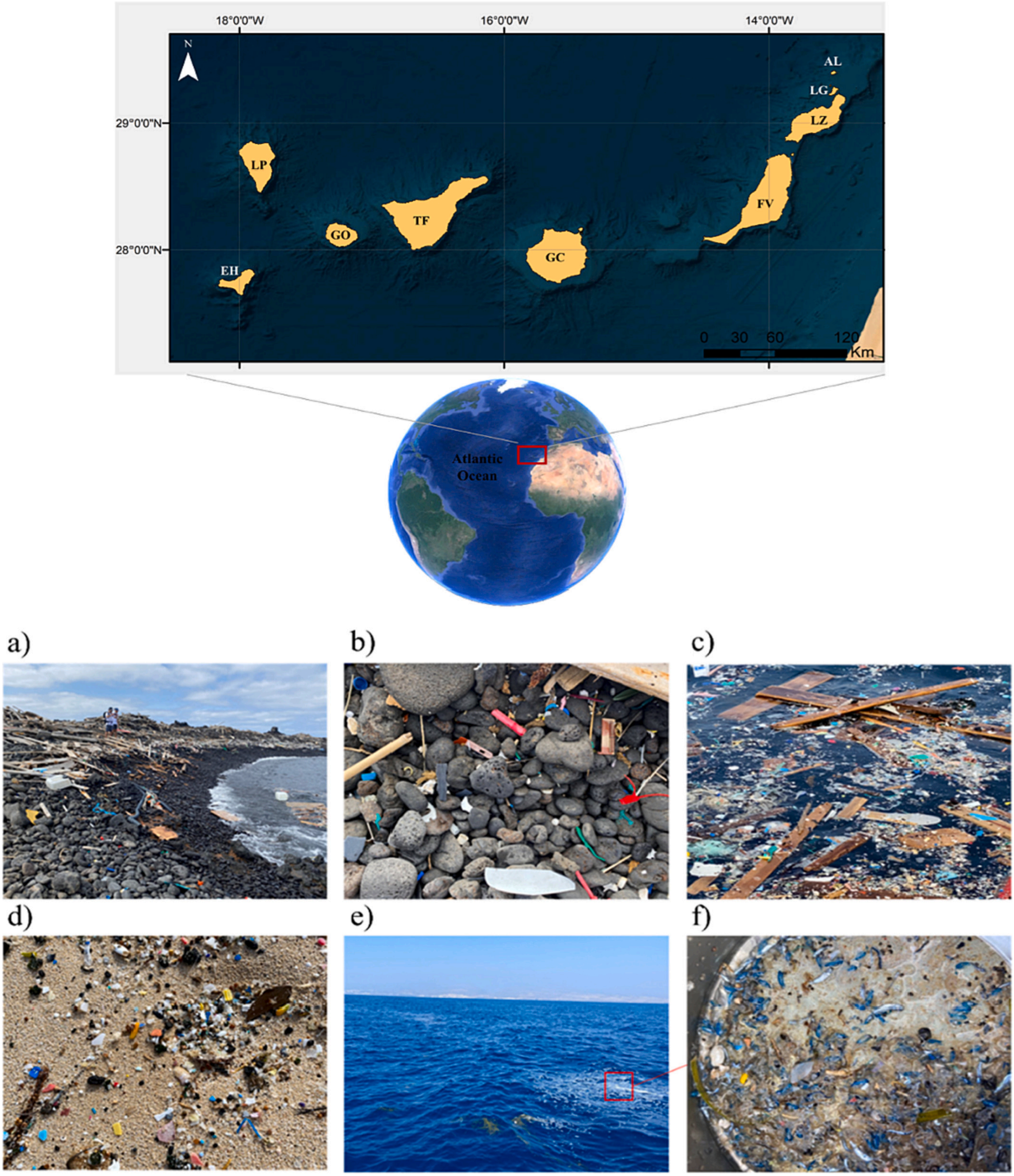


**Fig. 1.** Top panel: Geographical situation of the Canary Islands: La Palma (LP), El Hierro (EH), La Gomera (GO), Tenerife (TF), Gran Canaria (GC), Fuerteventura (FV), Lanzarote (LZ), La Graciosa (LG) and Alegranza (AL). Bottom panels: Photos of marine plastic pollution in coastal areas of Canary Islands, from top left: Beach of Alegranza Island in the Chinijo archipelago (a), detail of plastics in Alegranza (b), detail of litter floating in Alegranza (c), detail of microplastic in the wrack line in the beach "Playa Lambra" (La Graciosa) (d), marine litter windrow (MLW) in the south of Gran Canaria (e), and sample collected in a MLW in Gran Canaria (f). Photo credit: R. Almeda.

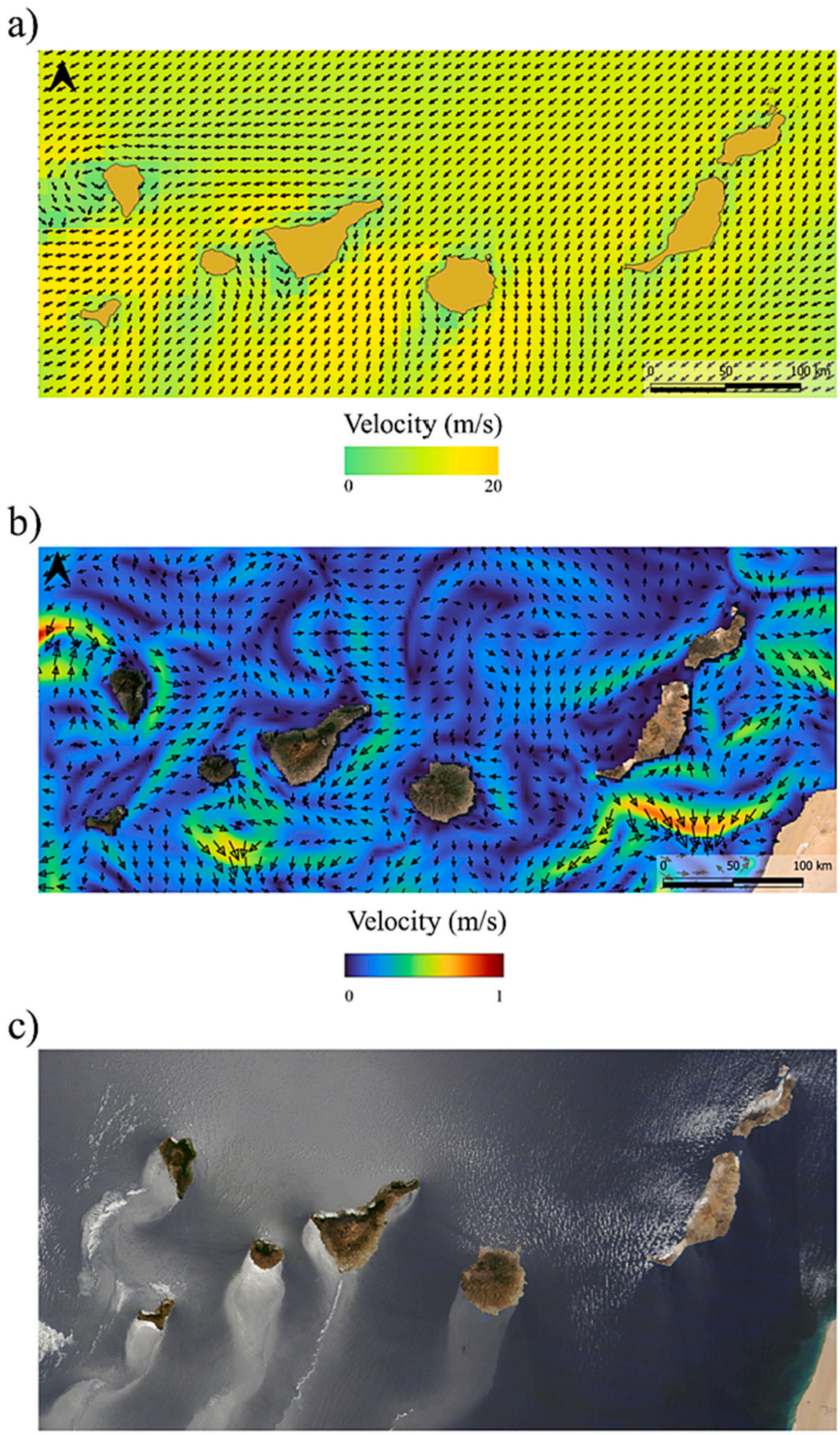


**Fig. 2.** (a) Average wind (direction and intensity) of the Canary Islands generated using wind data from Copernicus Marine Service Information (2022b). Date between 02/07/2020 to 20/11/2022. (b) Average currents (direction and intensity) of the Canary Islands generated using velocity data from Copernicus Marine Service Information (2022a). Data between 02/12/2020 to 20/11/2022. (c) Image from the MODIS sensor onboard TERRA satellite showing the wavy, windsock-like tails stretching to the southwest of the Canary Islands, caused by the winds roughening or smoothing the water's surface. Prevailing winds in the area come from the northeast, and the rocky volcanic islands create a sort of wind shadow, which results in calmer surface waters in southwest of the islands (leeward zones) that change how light is reflected (NASA, 2013).

the North Atlantic to the Canary Islands, making the archipelago especially vulnerable to plastic pollution (Baztán et al., 2014) (Fig. 1). The presence of plastic debris in coastal environments in the Canary Islands has been documented in the literature (Baztán et al., 2014; Herrera et al., 2018; Álvarez-Hernández et al., 2019; Edo et al., 2019; González-Hernández et al., 2020; Rapp et al., 2020; Reinold et al., 2020; Hernández-Sánchez et al., 2021; Herrera et al., 2022; Villanova-Solano et al., 2022). Baztán et al. (2014) was the first study to point out the high concentration of plastics found in some beaches facing north and northeast in the western islands (e.g., Playa Lambra in La Graciosa, Famara in Lanzarote). Similarly, plastic pollution in other beaches in the Canary Islands has been reported (Herrera et al., 2018; Álvarez-Hernández et al., 2019; González-Hernández et al., 2020; Reinold et al., 2020; Hernández-Sánchez et al., 2021). These studies corroborate that the archipelago is highly exposed to plastic pollution from remote sources due to the Canary Current.

The currently available data on plastic pollution in the Canary Islands are dispersed, and it is necessary and timely to compile the available information on plastic pollution in this archipelago to better evaluate both the degree of plastic pollution and research needs. Here we compile and analyze the published data on meso- (5–25 mm) and microplastics (MPs, 1 μm–5 mm) (Frias and Nash, 2019) in the Canary Islands over the last decade. Due to their availability, we focused our analyses on data from surface waters and beaches. Specifically, we aim to assess the status of meso- and microplastic pollution in the Canary Islands, the degree of coastal and seawater pollution among islands and between leeward and windward zones, and the main characteristics of marine MPs found in the Canary Islands. We also compare the level of plastic pollution in the Canary Islands with other oceanic islands. Finally, we identify knowledge gaps and provide recommendations for future research to better evaluate plastic pollution in the Canary Islands.

## 2. Methodology

We used the Web of Science (WOS) to find the bibliography regarding plastic pollution in the Canary Islands. We used the combination of the keywords "marine debris", "plastics", and "microplastics" with "Canary Islands" and we found 55, 83, and 40 results respectively (on July 10, 2023). From that search, 26 articles were relevant to the goals of this study. The literature on plastic pollution in the Canary Islands was first divided according to the environmental compartment investigated as follows: beach, biota, sediment, surface water, and water column. To accomplish the objectives of this study, we focused on the publications regarding plastic pollution in coastal areas/beaches and surface waters due to the number of studies and their spatial feature. From these studies, we obtained data on the concentration of meso- and microplastics in beaches (S.I. Table S1), data on surface water concentration of MPs (S.I. Table S2), types, colours, and polymer types (S.I. Table S3). When it was possible, we homogenized the units of plastic abundance (in items and mass) to elaborate the maps and figures for comparison between sampling points and islands. Raw data from Baztán et al. (2014) were not available, thus we used the mass ranges provided in Figs. 6 and 7 of his study.

Beach concentration data by island and windward-leeward zones were analysed using the R 4.1.2 Statistical Program (R Core Team, 2021). The Shapiro-Wilk test was used to verify the normality of the data after using Box-Cox Transformation. Homoscedasticity of variance was tested using the Levene test. Subsequently, we used the *t*-test for comparison between leeward vs windward zones and the ANOVA tests to determine statistical differences among islands. We used R 4.1.2 employed RStudio 2022.07.2 + 576 (R Core Team, 2021) to make the graphics, and ArcMap 10.7 and QGIS 3.28 to elaborate the maps.

## 3. Results

### 3.1. Research trends on plastic pollution in the Canary Islands

The number of publications on plastic pollution in the Canary Islands has notably increased during the last few decades (Fig. 3a). The studies mainly focused on beach and surface water as well as biota, whereas the data on sediments and in the subsurface/water column are very limited (Fig. 3b). Regarding the number of studies per island, Tenerife, Gran Canaria, and Lanzarote were the islands with the greatest research focus. Conversely, published studies on the other islands are scarce, particularly in La Palma (Fig. 3c). Fourier-transform infrared spectroscopy (FTIR) was the common technique for the identification of synthetic polymers in all the studies. Sampling on beaches was conducted in the high tide lines (strandlines) but with some methodological variations among studies (S.

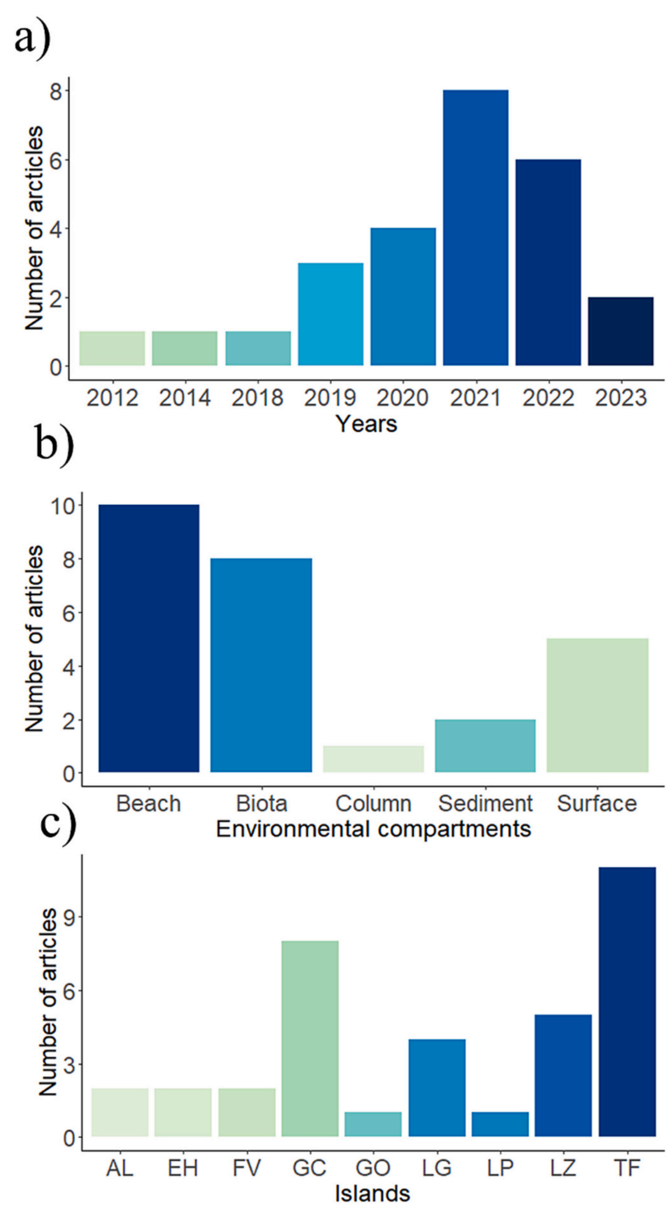


**Fig. 3.** (a) Number of annual publications on meso- and microplastic pollution in the Canary Islands. (b) Number of articles of meso- and microplastics by environmental compartments (column = water column, surface = surface waters) (c) Number of publications on meso- and microplastics by islands. Alegranza (AL), El Hierro (EH), Fuerteventura (FV), Gran Canaria (GC), La Gomera (GO), La Graciosa (LG), La Palma (LP), Lanzarote (LZ) and Tenerife (TF).

I. Tables S1 and S6). In all cases, the concentration, type, and colour of micro- and mesoplastics was determined by visual characterization and/or microscopy (S.I. Tables S1 and S6). The mass of beached plastics in all the reviewed studies was determined directly by weighting except for one study (Rapp et al., 2020) where an extrapolation was used. In all the reviewed studies a manta net (mesh size of 200 μm) was used as a common methodology to collect MPs from surface waters (<30 cm) in the Canary Islands (S.I. Tables S2 and S7).

### 3.2. Concentrations of meso- and MPs in beaches and surface waters

Based on the available data, the concentration of plastic on beaches was highly variable, ranging from 1.5 to 2971 items/m$^2$ with a mean of 381 ± 721 items/m$^2$ (Table 1). The highest concentrations of beached plastics both in number and mass tended to be in the windward zones of the islands (Fig. 4a–b). The highest concentration in items/m$^2$ was found in Tenerife in Playa Grande and La Graciosa in Playa Lambra (Fig. 4a). When considering the plastic mass found on beaches (g/m$^2$), Fuerteventura, Lanzarote, and La Graciosa show the highest levels of pollution with many sampling points at >120 g/m$^2$ (Fig. 4b). Playa Grande in Tenerife and Arenas Blancas in El Hierro, were the most polluted sites in the western islands (Fig. 4b). We did not find available data on the concentrations of plastics in coastal zones of La Palma and La Gomera (Fig. 4a–b).

The concentration of plastic in surface waters ranged from 21.3 × 10$^3$ to >17 million items/km$^2$ with a mean of 998 × 10$^3$ ± 3364 × 10$^3$ items/km$^2$ and 10 ± 31 items/m$^3$ (Table 1). The highest concentrations of MPs tended to be found in the leeward zones of the islands of high elevation (Tenerife, Gran Canaria, and La Gomera) (Fig. 5). We did not find available data on the concentrations of MPs in the surface waters of La Palma and only one study in El Hierro (Campillo et al., 2023).

**Table 1**
Summary statistics of the available data on micro- and mesoplastic abundance in beaches and surface waters of the Canary Islands. Detailed data of all studies conducted in the Canary Islands and used for these summary statistics are given in the SI (Tables S1–S2).

| Compartment | Units | Minimum | Maximum | Average | Standard deviation | Median |
|---|---|---|---|---|---|---|
| Beaches | items/m$^2$ | 1.5 | 2971.5 | 381.02 | 721.44 | 70 |
| | g/m$^2$ | 0.0011 | 99.0 | 11.78 | 21.40 | 2.9 |
| Surface Water | items/km$^2$ | 21,326 | 17,245,322 | 998,075 | 3,364,302 | 119,940 |
| | items/m$^3$ | 0.30 | 137.96 | 10.31 | 31.35 | 0.910 |

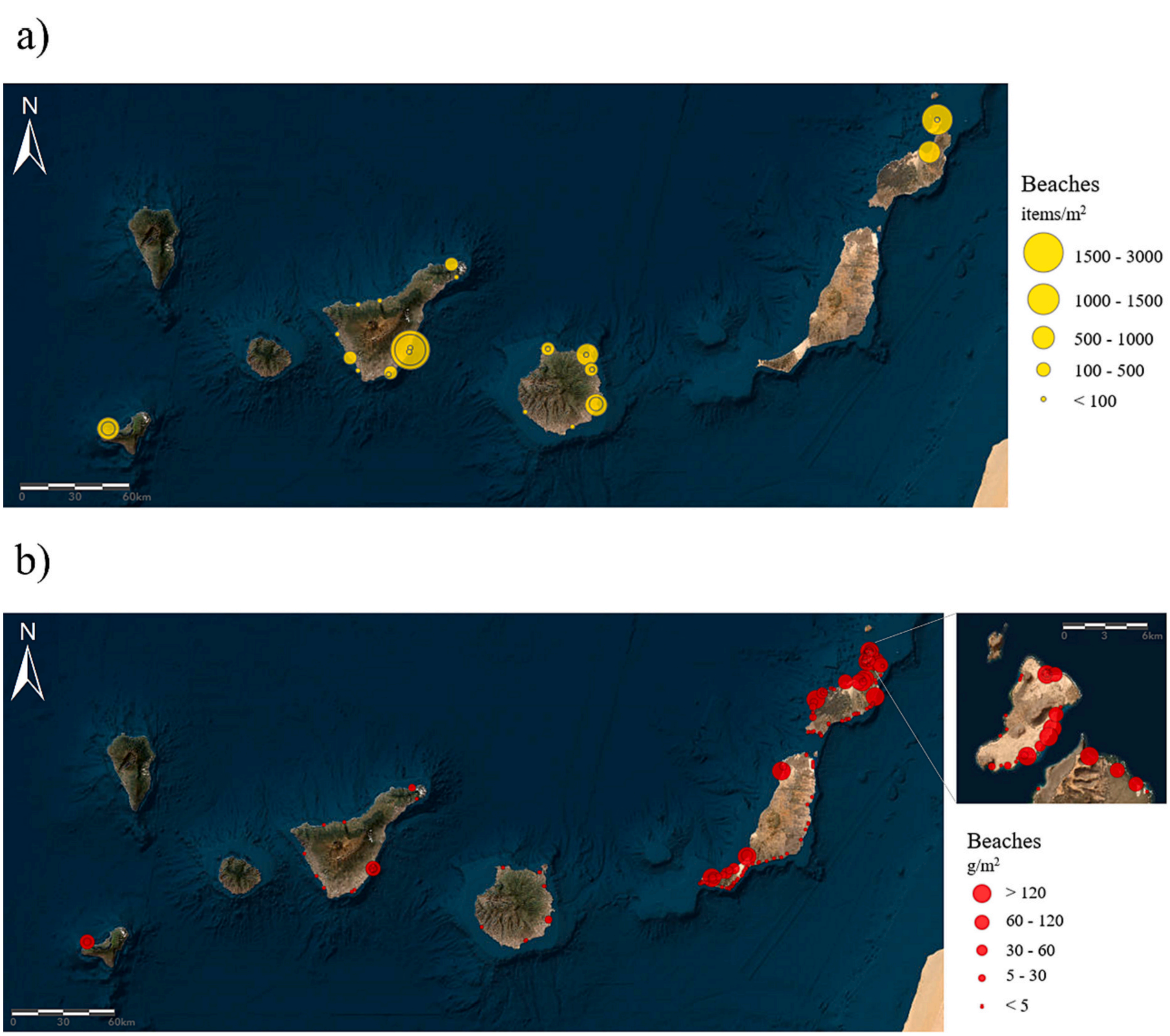


**Fig. 4.** The abundance of micro- and mesoplastics on beaches of the Canary Islands in in items per m$^2$ (a) and in g per m$^2$ (b).

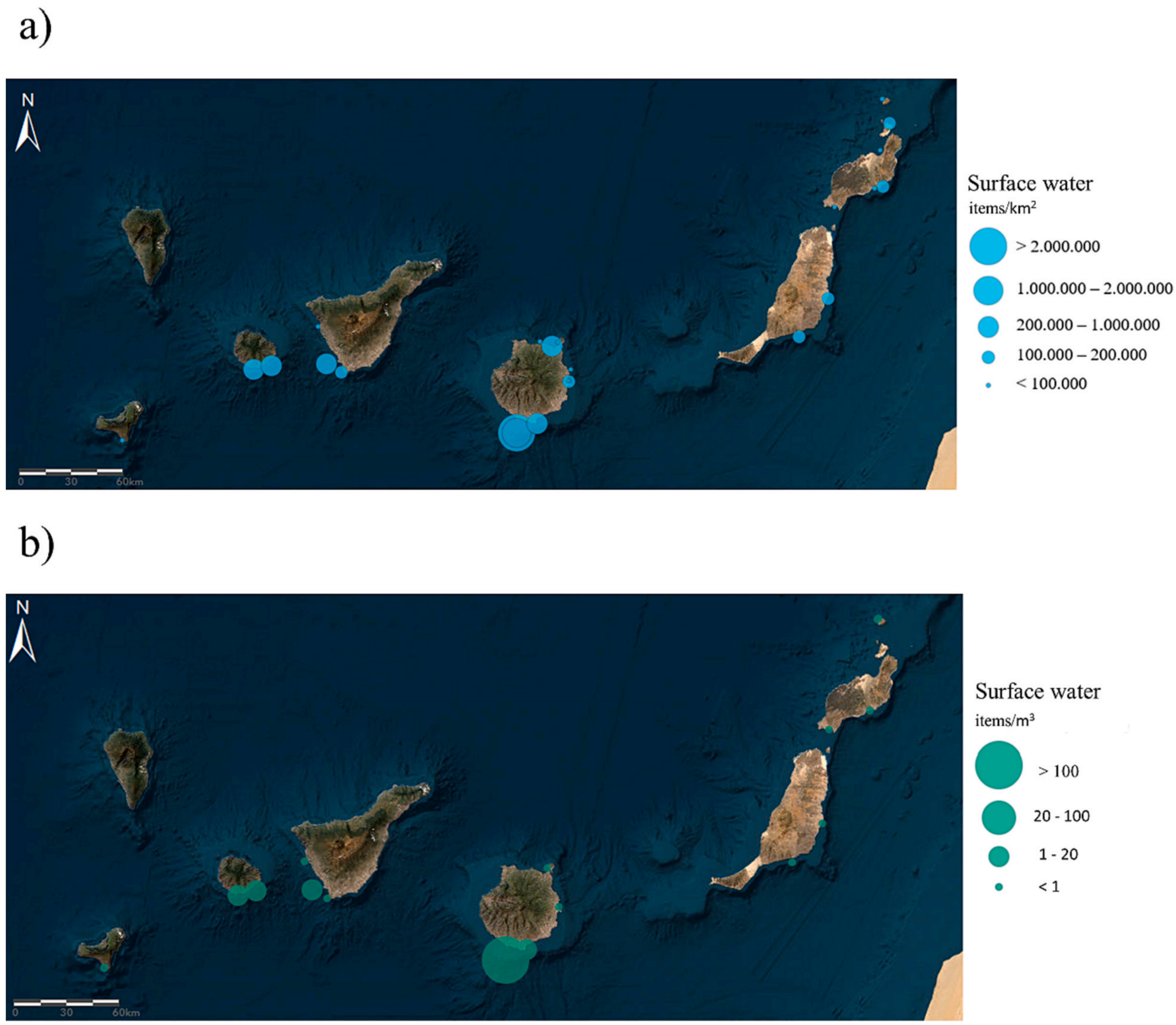


**Fig. 5.** Abundance of microplastics (>200 μm) in surface waters of the Canary Islands in items per $km^2$ (a) and in items per $m^3$ (b).

### 3.3. Comparison of plastic pollution among islands

Overall, we found notable differences in sampling efforts among islands (n), high variability in terms of concentrations among and within sampling sites, and limited data for some islands. Considering the available data, we found that the median levels of pollution on beaches are typically below 25 g/$m^2$ for all the islands, except for a sampling in El Hierro when the mass of plastics was approx. 35 g/$m^2$ (Fig. 6a). The concentrations of plastics were commonly below 500 items/$m^2$, with some "outliers" corresponding to plastic concentrations of up to 3000 items/$m^2$ found mainly in Playa Grande (Tenerife) (Fig. 6b). The highest concentrations of MPs collected with manta net were found in Tenerife, Gran Canaria, and La Gomera, with a median of 5.42, 5.35, and 5.61 items/$m^3$, respectively (Fig. 6c). The concentration of MPs in items/$km^2$ shows the same pattern, except for Fuerteventura, which show a higher concentration in this case (Fig. 6d). The results of the ANOVA to test significant differences in concentration of beached MPs among islands, including La Graciosa, Gran Canaria, Tenerife and El Hierro (islands with $n \geq 2$) showed a non-significant difference ($p > 0.05$) in both items/$m^2$ and g/$m^2$ among islands.

### 3.4. Comparison between windward and leeward zones

The accumulation of plastic debris in windward beaches was one order of magnitude significantly higher than in the leeward zones (Fig. 6e–f). Regarding the comparisons between the windward beaches (Lambra, Famara, Las Canteras, La Laja, Cuervitos, El Porís, Los Abriguitos, Leocadio Machado, Las Gaviotas, Almáciga, Playa Grande and Arenas Blancas) and leeward beaches (Playa del Águila, Veneguera, Bocabarranco, San Marcos, El Socorro, La Tejita, El Puertito de Adeje, Las Vistas y La Arena), we found significant differences depending on the beach orientation both in items and mass concentrations (*t*-test < 0.05) (Fig. 6e–f). Data on MP concentration in windward surface waters in the Canary Islands are scarce (Fig. 5), but the highest concentrations of MPs in water were found in the leeward zones of the islands of high elevation (Tenerife, La Gomera, and Gran Canaria) as mentioned above.

### 3.5. General characteristics of meso- and microplastics in the Canary Islands

Regarding the characteristics of the data (S.I. Table S3), microplastics were approximately half of the plastic debris collected in the beach samples (Fig. 7a). All the plastics in surface water samples fall under the category of MPs (<5 mm). Fragments were the dominant

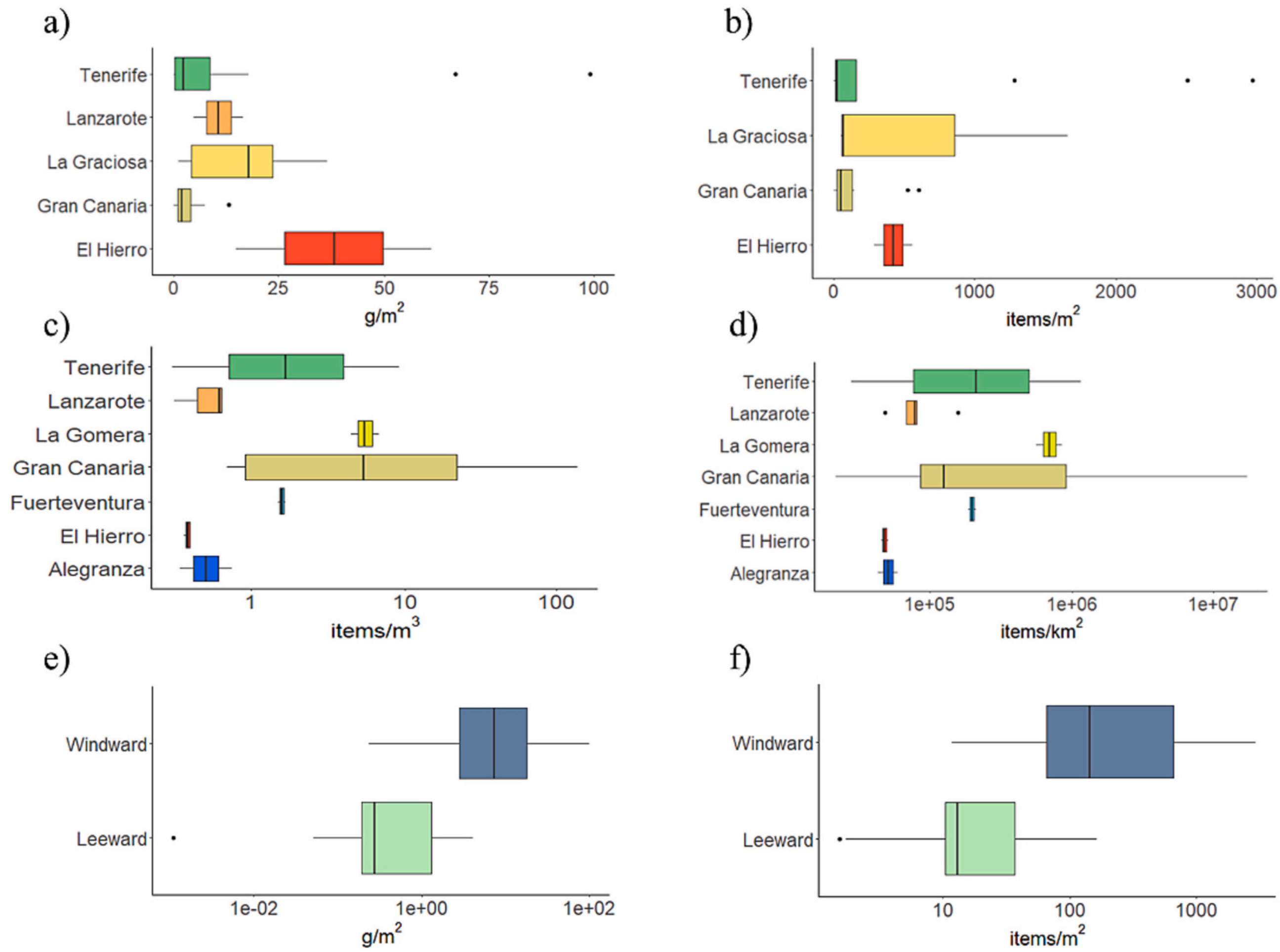


**Fig. 6.** Abundances of micro- and mesoplastics in different Islands and zones (windward vs leeward) in the Canary Archipelago. (a) Micro and mesoplastics on beaches in g by $m^2$. Data from Baztán et al. (2014) was not included because not available. (n Tenerife = 16, n Lanzarote = 2, n La Graciosa = 5, n Gran Canaria = 12, n El Hierro = 2). (b) Micro and mesoplastics on beaches in items by $m^2$ (n Tenerife = 15, n La Graciosa = 3, n Gran Canaria = 12, n El Hierro = 2). (c) Microplastics in surface water in items by $m^3$ (n Tenerife = 3, n Lanzarote = 3, n La Gomera = 2, n Gran Canaria = 5, n Fuerteventura = 2, n El Hierro = 2, n Alegranza = 2). (d) Microplastics in surface water in items by $km^2$ (n Tenerife = 3, n Lanzarote = 5, n La Gomera = 2, n Gran Canaria = 9, n Fuerteventura = 2, n El Hierro = 2, n Alegranza = 2). Comparison between the plastic concentrations in windward and leeward zones in (e) g per $m^2$ and (f) items per $m^2$. The central thick line of each boxplot shows the median and the box height shows the interquartile range.

plastic type found in beaches and surface water (72.2 % and 83.3 %, respectively). Pellets (15 %) were the second most abundant plastic type in beaches and fibers represent only 4.3 % of the total MPs in surface water samples collected with the manta net (Fig. 7b–c). In terms of colour, the category of No Colour/White/Clear was the most abundant in both beaches (61.9 %) and surface waters (57.6 %) (Fig. 7d–e). In the case of polymers, polyethylene (PE-HDPE) was the most abundant in both cases (56.8 % beaches, 64.7 % surface waters), followed by polypropylene (PP, 25.7 % beaches, 28 % surface waters) (Fig. 7f–g).

## 4. Discussion

### *4.1. Distribution of marine plastic pollution in the Canary Islands*

#### *4.1.1. Influence of oceanography and topography: windward vs leeward zones*

Lagrangian simulations and floating drifter trajectories indicate that part of the plastic debris found in the Canary Islands is from remote, exogeneous sources, including the North Atlantic "garbage patch" (Cardoso and Caldeira, 2021). Plastic tags from lobster traps across the North American Atlantic coasts have been found in the Canary Islands, supporting the role of the oceanic circulation and currents as driving forces responsible for transporting plastic litter to the Canary Islands (Cividanes et al., 2024). Other studies also suggest that local sources (e.g., wastewater effluents) can contribute to microplastic pollution in coastal areas of the Canary Archipelago (Baztán et al., 2014; Rapp et al., 2020).

The concentrations of micro- and mesoplastics on beaches in the windward zones were one order of magnitude higher than in leeward zones; this was expected in the Canary Archipelago since the Canary Current intercepts the islands in these windward zones. A similar pattern has been found in other archipelagos such as Hawaii (Brignac et al., 2019), New Zealand (Bridson et al., 2020), Fernando de Noronha (Carvalho et al., 2021), and Yasawa (Al Nabhani et al., 2022). Altogether, these studies emphasize the important role of oceanic currents in the distribution and fate of plastic pollution from remote sources. The trade winds and their associated wind-driven surface currents are permanent in the Canary Islands, but their intensity varies among seasons (Cardoso and Caldeira, 2021) and the wind pattern can be affected by monsoons (Cropper et al., 2014). These factors can influence the arrival of plastic debris to windward and leeward zones in the Canary Archipelago.

Although there is not enough data to make a statistical analysis, the leeward zones of the high-elevation islands seem more susceptible to the accumulation of MPs in surface waters. This can be explained by the topography of the islands, which causes the presence of calm water zones in the leeward zones where MPs coming with the currents can accumulate

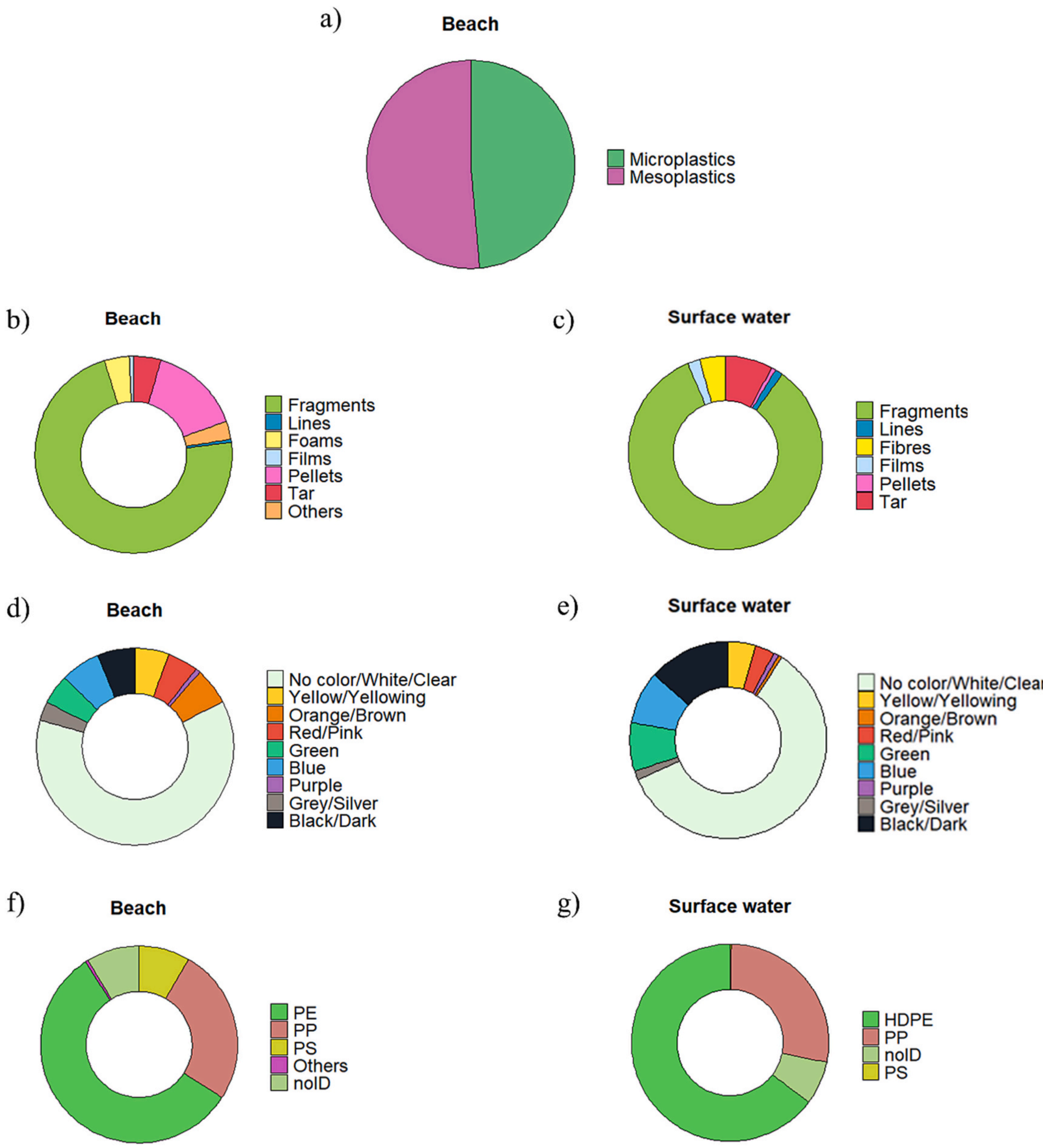


**Fig. 7.** Characterization of meso- and MPs in coastal areas of the Canary Islands. (a) Percentages of each size category (meso- vs microplastics) on beaches. Percentages of plastic types on (b) beaches and (c) surface waters. Percentages of colours on (d) beaches and (e) surface water. Polymeric composition in (f) beaches and (g) surface waters.

in these marine waters. These areas are prone to the formation of Marine Litter Windrows (MLW), an aggregation of floating litter at the sub-mesoscale domain, regardless of the force inducing the surface convergence, be it wind or other forces such as tides or density-driven currents (Cózar et al., 2021). The highest concentration recorded for MPs > 200 μm in the Canary Islands corresponds to this type of plastic litter accumulation found in surface waters in the south of Gran Canaria in October 2021 (Campillo et al., 2023). This finding emphasizes the importance of studying MLW to better understand their formation, distribution, and potential impacts on marine biota (Cózar et al., 2021; Campillo et al., 2023).

*4.1.2. What Canary Island has the highest level of plastic debris pollution?*

Plastic pollution in the Canary Islands shows a high regional and temporal variability. Considering the available data on meso- and microplastic pollution per island and their high variability, it is challenging to evaluate what islands are generally more polluted. Based on the study of Baztán et al. (2014) (only ranges of plastics in g/m$^2$ are provided), Fuerteventura, Lanzarote, and La Graciosa are the islands with an overall high mass of plastics, particularly in the windward beaches. One additional factor influencing the high amount of plastic on some beaches in the eastern islands is the presence of long sandy beaches, which can enhance the accumulation of microplastics (Troll and Carracedo, 2016). Although there is no data on MPs, the inhabited and ecologically important island of Alegranza, the northernmost islet of the Canary Archipelago, is the first obstacle of the Canary Current and shows a high accumulation of plastic macro-debris (Herrera et al., 2022). Regarding the western islands, there were no significant differences in the median number of beached plastics among the islands. The coasts of these islands are rockier, and the number of sand beaches is lower compared with the eastern islands. However, Playa Grande in Tenerife has one of the highest found average concentrations of beached MPs in the world, with almost 3000 items/m$^2$ (Álvarez-Hernández et al., 2019). Hotspots of plastic contamination have been also observed in the low-populated western island of El Hierro (Hernández-Sánchez et al., 2021) indicating that western islands are also susceptible to plastic pollution. Therefore,

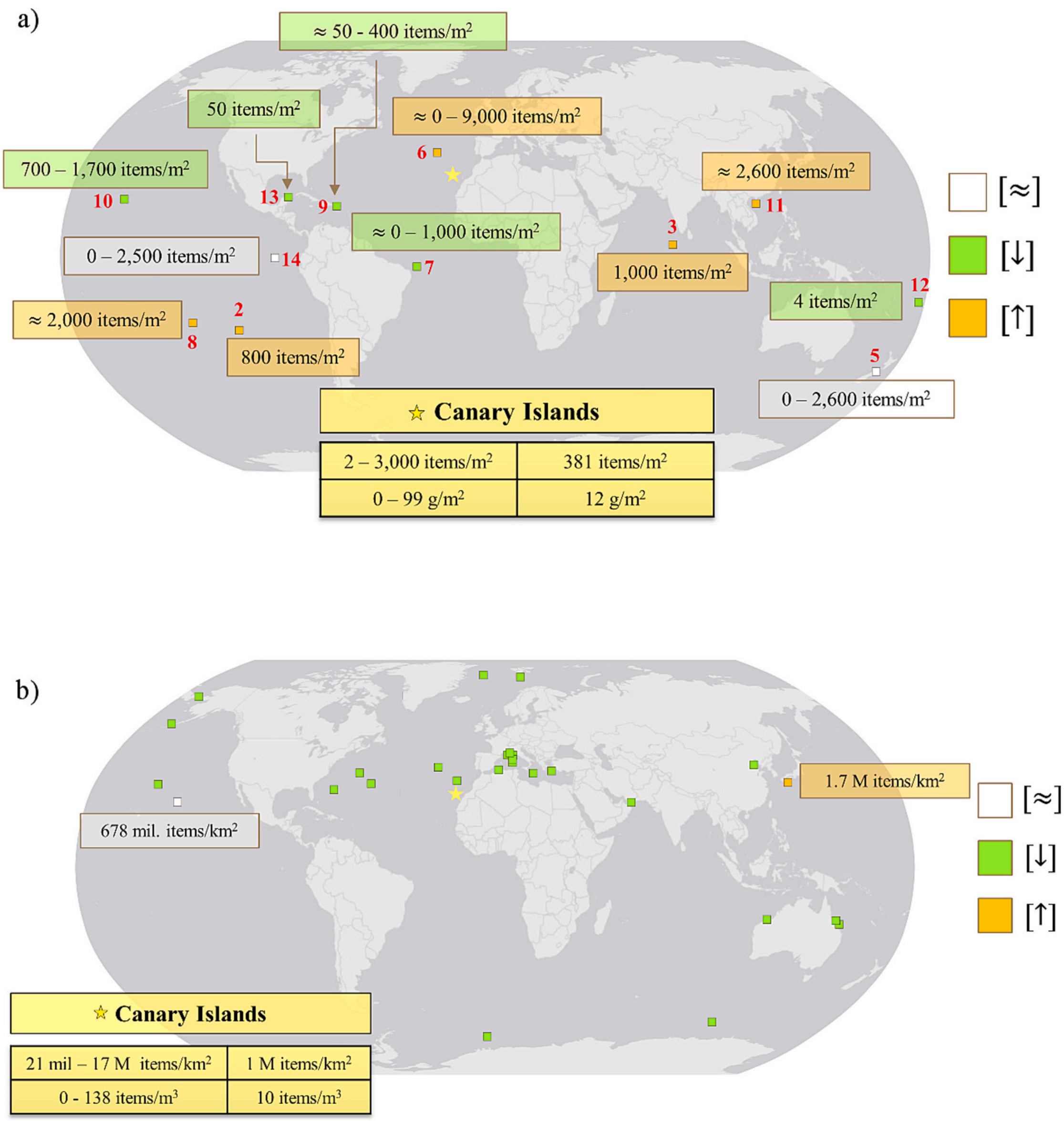


**Fig. 8.** Comparison of plastic pollution in the Canary Islands with other coastal regions globally: (a) the meso- and microplastic concentrations in beaches, with the numbering of Table S4 of the Supporting Information and rounded data from these studies. In the table below, as a reference the data (range and mean) from the Canary Islands, in items/m$^2$ and g/m$^2$ (yellow star). White rectangles correspond to areas where the concentrations are similar, green rectangles to lower concentrations, and orange rectangles to higher concentrations. (b) Concentration of microplastics in surface waters. In the table below, as a reference the data (range and mean) from the Canary Islands, in items/km$^2$ and g/m$^3$ (yellow star). White rectangles correspond to areas where the concentrations are similar, green rectangles to lower concentrations and orange rectangles to higher concentrations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

local accumulation of meso- and MPs occurs in all the islands, showing a relatively similar level of plastic pollution from remote sources.

### *4.2. Characteristics of meso- and microplastics in the Canary Islands*

Plastic fragments were the most common type of microplastics found both in surface waters and beaches of the Canary Islands, which is in line with the findings from other studies in other regions (e.g., Hidalgo-Ruz and Thiel, 2013; Lozoya et al., 2016). However, other studies have found that synthetic microfibers, mostly from textiles, are the dominant shape of MPs in surface waters (Lusher et al., 2015; Gago et al., 2018; Mu et al., 2019; Aigars et al., 2021). In a global analysis, Kannankai et al. (2022) indicate that the abundance of small marine microfibers in the environment has been underestimated during their chemical characterization with FTIR, likely due to their smaller surface area. Plastic pellets were the second most abundant type of plastic on beaches, showing the relevance of this type of plastic pollution discharged in the ocean during its production or transportation (Karlsson et al., 2018). As found in this review, most studies are conclusive about the predominance of white colour in marine microplastics (Kunz et al., 2016; Brignac et al., 2019; Mu et al., 2019; Carvalho et al., 2021) with some exceptions where black (Lusher et al., 2015) and blue plastics (Aslam et al., 2020) were found to be dominant.

Regarding the microplastic polymer composition, polyethylene (PE) polypropylene (PP), and polyamide (PA) have been reported as the most abundant types of plastic polymers in the marine environment (Kannankai et al., 2022). PE and PP were also dominant in coastal areas of the Canary Islands, as found in other areas on beaches (Martins and Sobral, 2011; Lozoya et al., 2016; Brignac et al., 2019), and in surface waters (Suaria et al., 2016; Lebreton et al., 2018; Poulain et al., 2019).

MPs as polyethylene can have different densities; interestingly, Brignac et al. (2019) found that HDPE (High-Density Polyethylene) dominated sea surface waters, while LDPE (Low-Density Polyethylene) dominated windward beaches. Also, Gunaalan et al. (2023) found that fragments (<300 μm) of high-density polymers were the dominant MPs in the water column. However, in other studies, polyester (PES), mostly microfibres, has been reported as the predominant microplastic polymer (e.g., Barrows et al., 2018; Rist et al., 2020; Gunaalan et al., 2023). The polymer composition can also vary among size-fractions of MPs (Rist et al., 2020), and as mentioned above, the abundance of PES microfibers can be underestimated in some studies (Kannankai et al., 2022). The polymeric composition of marine MPs can vary regionally and depends on the used methodologies and examined size- fractions of MPs.

Recent studies indicate that tire wear particles (TWP) are one of the major sources of MPs in the ocean (Boucher and Friot, 2017; Kole et al., 2017; Baensch-Baltruschat et al., 2020; Rødland et al., 2022), however, there is no available data on the concentration of TWP in coastal areas of the Canary Island. TWP cannot be detected by regular FTIR and μ-FTIR analyses for conventional plastics, and therefore the development of a proper methodology for the quantification of TWP in the marine environment is required (Mengistu et al., 2019).

### *4.3. Is the Canary Archipelago a global hotspot of oceanic plastic pollution?*

It is important to be cautious when comparing results among different studies due to differences in sampling methodologies and frequencies, seasonality, and quality assurance (S.I. Tables S1–S7). Keeping this in mind, in most studies beached *meso* and microplastics were sampled from the first centimetres of sand (1–5 cm) in high tide lines (strandlines) using grids. Their abundance of meso and microplastics (>1 mm) and their polymer composition was commonly estimated by the naked eye/microscopy and FTIR, respectively, allowing comparability among studies. When we consider the reported concentrations of meso- and MPs found on beaches of the Canary Islands (Table 1) in a global context, we found that the levels of plastic pollution in the Canary Archipelago are intermediate. For example, higher amounts of microplastic pollution have been found in highly populated coastal areas such as Hong Kong (5595 items/m$^2$, Fok and Cheung, 2015), Algeria (Grini et al., 2022), Portugal (Martins and Sobral, 2011) and China (Qiu et al., 2015). Other studies have shown other coastal areas with lower mean microplastic pollution than the Canary Islands such as the Gulf of Guinea (Fred-Ahmadu et al., 2022), Guatemala (Mazariegos-Ortíz et al., 2020), Slovenia (Laglbauer et al., 2014) and South Korea (Lee et al., 2017). Overall, these data show that, although the level of pollution varied regionally, microplastic pollution is a global problem with both land-based and remote oceanic sources influencing the accumulation of plastics in coastal areas.

Focusing on the comparison with other oceanic islands, mostly affected by oceanic litter, (Fig. 8a, S.I. Table S4) and considering studies on beached microplastics reported with the same units (items/m$^2$ or g/m$^2$), we found studies reporting relatively similar ranges and means of plastic pollution in the Galapagos Islands (Jones et al., 2022), New Zealand, (Bridson et al., 2020), and the Fernando de Noronha Archipelago (Carvalho et al., 2021). Lower concentrations of beached MPs than in the Canary Islands were found in Hawaii (Rey et al., 2021), Puerto Rico, (Pérez-Alvelo et al., 2021), Yasawa Archipelago (Fiji), (Al Nabhani et al., 2022) and Holbox Island (Mexico) (Cruz-Salas et al., 2022). Higher concentrations have been reported in the Azores Islands, (Pham et al., 2020), Easter Island (Chile), (Hidalgo-Ruz and Thiel, 2013), Maldives (Imhof et al., 2017), Henderson Island (Nichols et al., 2021) and Hainan Island, (Zhang et al., 2021). Taking all this into account, the mean level of microplastic pollution on beaches of the Canary Islands is within the higher ranges for islands, globally. This is in line with the global analyses of plastic litter by Hardesty et al. (2021) where the Canary Islands was ranked number 1 of the 10 top places more polluted by anthropogenic debris and plastic pieces on the land/coast.

Considering the available data and their concentration units, the concentration of MPs in surface waters of the Canary Islands (min-max: 0.30–138 items/m$^3$, mean: 10 items/m$^3$) is generally much higher than in other oceanic Islands or coastal regions (Fig. 8b – S.I. Table S5). The MP concentrations in the Canary Islands reported in items/km$^2$ (max-min of 21,326–17 M items/km$^2$, mean of 998,075 items/km$^2$) are close to those observed in the North Pacific Subtropical Gyre (Lebreton et al., 2018) and only surpassed by the East Asian Sea, with an average of 1,720,000 items/km$^2$ (Isobe et al., 2015). Considering the available data of MP concentrations in items/m$^3$ (Montoto-Martínez et al., 2022; Campillo et al., 2023), the concentration of MPs in marine surface waters in the Canary Islands is 10 times higher than those reported for other coastal areas (S.I. Table S5). These data indicate that the Canary Islands is a hotspot of marine microplastics in surface waters, globally. However, it is important to note that the mesh-size of the manta nets employed in other studies was larger (330 μm) than the ones used in the Canary Islands (200 μm) (Table S5). This can influence the concentration of the net-collected microplastics, which would decrease with increased mesh size (Lindeque et al., 2020). Nevertheless, when comparing between studies where a manta net with a similar mesh-size of 200 mm was used (Table S5), the concentrations of MPs found in the Canary Islands were an order of magnitude higher than in other regions such as Madeira and the Mediterranean Sea (Table S5).

### *4.4. Research needs to better assess the level and potential effects of plastic pollution*

Although studies on plastic pollution in the Canary Islands have increased in the last decade, more publications on this topic are needed to make a better assessment of the pollution levels and trends in this region. More field studies of MP pollution on marine sediments, water columns, and surface waters in areas of accumulation of plastics (e.g. MLW) are needed. It is important to continue monitoring and increasing the research efforts in the islands of Alegranza, El Hierro, Fuerteventura, La Gomera, and La Palma, where data on MP pollution is very limited. In addition, it would be important to strategically select sampling points to compare windward and leeward areas, and with a proper sampling frequency, to evaluate seasonal variation in plastic pollution in the Canary Islands and the influence of oceanographic conditions and mesoscale processes on the dispersion and accumulation of MPs in the archipelago. Standardization of the units (e.g., items/m$^2$ for beaches, items/m$^3$ for surface water) and sampling methodologies in each environmental compartment are required for better comparability among studied sites. It is important to note that there is no published data on the small-size fractions of MPs (<200–300 μm) in the Canary Islands. MPs < 200 μm are not collected with commonly used manta nets, but they can represent up to 90 % of the total MPs in marine waters (Gunaalan et al., 2023).

The potential negative effects of plastic pollution on marine animals can be related to the ingestion of plastic debris (e.g., Duncan et al., 2019; Kühn and van Franeker, 2020), which is common in fish and marine birds of the Canary Islands (Herrera et al., 2019; Navarro et al., 2023). Also, plastics can release chemical additives to the water, which can be toxic to marine organisms (Hermabessiere et al., 2017; Almeda et al., 2023; Moreira et al., 2024) and bioaccumulate in predators (e.g., in killer whales, Desforges et al., 2018). The risk of these harmful effects on biota can be locally higher in areas of high accumulation of plastic debris. The highest concentrations of microplastics in surface waters (e.g., in the form of MLW) in the leeward zones of the Canary Islands occur in Special Areas of Conservation (ZECs) in the Canary Islands, such as "Franja Marina Santiago – Valle Gran Rey", south and southwest of La Gomera, "Franja Marina Teno-Rasca", southwest of Tenerife and "Franja marina de Mogán" and "Sebadales de Playa del Inglés", south and southwest of Gran Canaria (MITECO, 2022), which calls for increased monitoring of plastic pollution and MLW in these ecologically important marine areas of high biodiversity and cetacean sanctuaries (Herrera et al., 2021). Lastly, the occurrence, distribution, and fate of emerging-concern MPs and plastic litter such as tire wear particles and cigarette butts are unknown in the Canary Islands. These plastic residues are toxic to marine biota (Tian et al., 2021; Page et al., 2022; Bournaka et al., 2023; Rist et al., 2023; Lucia et al., 2023; Moreira et al., 2024) and can cause higher impacts on the ecosystems than conventional microplastics, and therefore deserve more attention.

## 5. Conclusions

The mean concentration of meso- and MPs on the studied beaches of the Canary Islands is 381 items/m$^2$ and 11.78 g/m$^2$, with a maximum of almost 3000 items/m$^2$ found in Playa Grande (Tenerife) in 2018. MPs are ubiquitous in surface waters of the Canary Islands, with average concentrations of 998,075 items/km$^2$ and 10 items/m$^3$. Coastal areas and beaches in the windward zone of the islands showed plastic concentrations one order of magnitude higher than in the leeward zones. The highest concentrations of MPs in surface waters have been recorded in the leeward zones in the islands with high altitudes, which correspond to ZECs of the Canary Islands. White/Uncoloured fragments of PE and PP were the most common type of meso- and MPs found in beaches and surface waters. The Canary Archipelago has numerous local hotspots of oceanic plastic pollution from remote sources in most of the islands, with values at the higher range compared with other islands and coastal regions, globally. These levels of meso- and microplastic pollution in the Canary Islands call for more research efforts and mitigation measures to reduce the ecological impacts of plastic pollution in this unique and high-biodiversity volcanic archipelago.

## CRediT authorship contribution statement

**Andrea García-Regalado:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Alicia Herrera:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Rodrigo Almeda:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization.

## 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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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2024.116230.

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