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First evaluation of neustonic microplastics in the Macaronesian region, NE Atlantic

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ABSTRACT

Marine microplastic pollution is an issue of great concern nowadays since high concentrations have been detected in the ocean, mainly in the subtropical gyres that accumulate this type of debris. The long-term effects of this pollution on ecosystems and marine biota are still unknown. The aim of this study is to quantify and characterise microplastics and neustonic zooplankton in sub-surface waters of the Macaronesian region, an area that has been little studied to date. Our results show a great variability in the concentration of microplastics with values between 15,283 items/km^2 in Los Gigantes (Tenerife, Canary Islands) and 1,007,872 items/km^2 in Las Canteras (Gran Canaria, Canary Islands). The main types of debris found were plastic fragments and fibres. The abundances of neustonic zooplankton were also very variable between the different sampling areas, being the main components copepods and eggs. Regarding the microplastics-zooplankton ratio, values were obtained between 0.002 and 0.22. In Las Canteras, the highest accumulation zone, was found twice as much microplastics as zooplankton for the 1–5 mm fraction in dry weight. These values highlight the potential hazard of microplastics – and its associated chemical contaminants – for marine biota, especially for large filter feeders.

1. Introduction

Large-scale plastic production has continued to grow from its beginnings in 1950 to the present day, reaching almost 350 million tonnes in 2017 (PlasticsEurope, 2018). The accumulation of this plastic waste and its entry into the ocean, estimated at 4.8 to 12.7 million metric tons per year (Jambeck et al., 2015), is one of the major environmental problems of the present time.

The United Nations Environmental Programme (UNEP) defines marine litter as “ any persistent, manufactured or processed solid discarded material, disposed of or abandoned in the marine and coastal environment” (UNEP, 2009), the great majority of these wastes are plastics, but glass, wood, tar, metal, natural fibres, etc. can also be found (Kroon et al., 2018). Nowadays, there is no consensus on the size that defines microplastics and microdebris, in 2009 NOAA proposes a definition in which microplastics are considered as all plastic particles with < 5 mm in diameter (Arthur et al., 2009), EU MSFD WG-GES (MSDF Technical Subgroup on Marine Litter, 2013) proposes > 20 and < 5000 μ m, and recently Hartmann et al. (2019) propose the size between > 1 and < 1000 μ m to define microplastics. In the present study, we use the term microdebris to describe particles of anthropogenic origin with a size less than 5 mm.

Pollution by microplastics is an issue of growing concern in the scientific community, environmental policy authorities and society due to the potential risk it may have for ecosystems, marine biota, human health and the economy. The topic is being widely studied at a global level, on the other hand, in the Macaronesian region although results are known in beaches (Álvarez-Hernández et al., 2019; Baztan et al., 2014; Chambault et al., 2018; Gestoso et al., 2019; Herrera et al., 2018; Ríos et al., 2018), and there are some studies on marine biota (Herrera et al., 2019b; Pham et al., 2014; Rodríguez and Pham, 2017; Rodríguez et al., 2012), microplastic contamination in sub-surface waters has been little studied.

The Macaronesia region is conformed by a group of islands located

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in the Eastern Atlantic, which form a biogeographic region. It includes more than 40 islands grouped into five archipelagos: Azores, Madeira, Selvagens, Canary Islands and Cape Verde. In total they occupy an area of more than 14,600 km ^{2}. The Macaronesian region has great biodiversity and many endemic species, 211 Sites of Community Importance (SCIs) and more than 65 Special Protection Areas (SPAs) have been declared (Sundseth, 2010). Due to their oceanographic situation close to the North Atlantic subtropical gyre (NASG), the islands are located at the flow of the Azores Current and the Canary Current, branches downstream of the Gulf Stream (Comas-Rodríguez, 2011). As a result, such oceanic islands are predicted to be particularly vulnerable to plastic pollution.

One approach of assess the potential risk of microplastics to marine organisms, particularly filter feeders, is to study the ratio between the amount of neustonic microplastics and zooplankton (Moore et al., 2001). This ratio increases in areas of the ocean with low productivity where the number of organisms decreases and the amount of plastic accumulates, such as in oceanic gyres.

For the above mentioned reasons, the main objectives of this study are to determine the abundance and characterize the floating microplastics in different zones of the Macaronesian region, and to study the microplastics-zooplankton ratio.

2. Materials and methods

2.1. Samples collection

A total of 45 neustonic samples were collected during daylight (9:00–14:00 h), 24 in the Canary Islands archipelago, 12 in Madeira and 9 in the Azores in the Macaronesian region (Fig. 1). Samples were collected in opportunistic samplings in different periods between 2015 and 2018. The collection dates and locations of each sample are shown in Table 3 of Supplementary material.

In the Canary Islands and Madeira, the neustonic samples were collected with a manta net with a rectangular mouth opening of 25 × 60 cm, and a 200 μ m mesh size. At each location, 3 samples were taken, except in Taliarte where only 2 samples were collected and in Los Gigantes where 4 samples were collected. The manta net was trawled at a speed of ~3 knots, during periods of 20 min. GPS coordinates were taken to measure the length of each transect. The net trawls were towed at a horizontal angle of 45° with respect to the ship's trails. Kukulka et al. (2012) demonstrated that in strong wind conditions the neuston net tends to collect less plastic particles because it is distributed vertically in the mixed layer due to wind-induced mixing. For this reason the sampling was only carried out under optimal sea conditions, with a Beaufort Sea Scale between 0 and 2.

In the Azores, three parallel transects were carried out at each site using 200 μ m mesh bongo nets 50 cm in diameter. Each tows lasted 2 min 20 s at a constant speed of ~2 knots. The volume of water filtered in the tows was calculated using a flowmeter only in Azores archipelago. The start and end coordinates were also recorded to determine the length of each transect.

Samples were collected and preserved in 4% of formaldehyde for later analysis.

2.2. Samples processing

All debris range from 0.2 to 5 mm were identified and counting by visual inspection under a binocular stereomicroscope (Leica S9i) with integrated CMOS camera, at 55× magnification. Microdebris were classified in different categories regarding its typology; irregular plastic fragments (Fragments), industrial pellets (Pellets), fibres (Fibres), films and sheets (Films), plastic microbeads (Microbeads), EPS and XPS (Foams), fishing lines (Lines) and others debris including glass, paint,

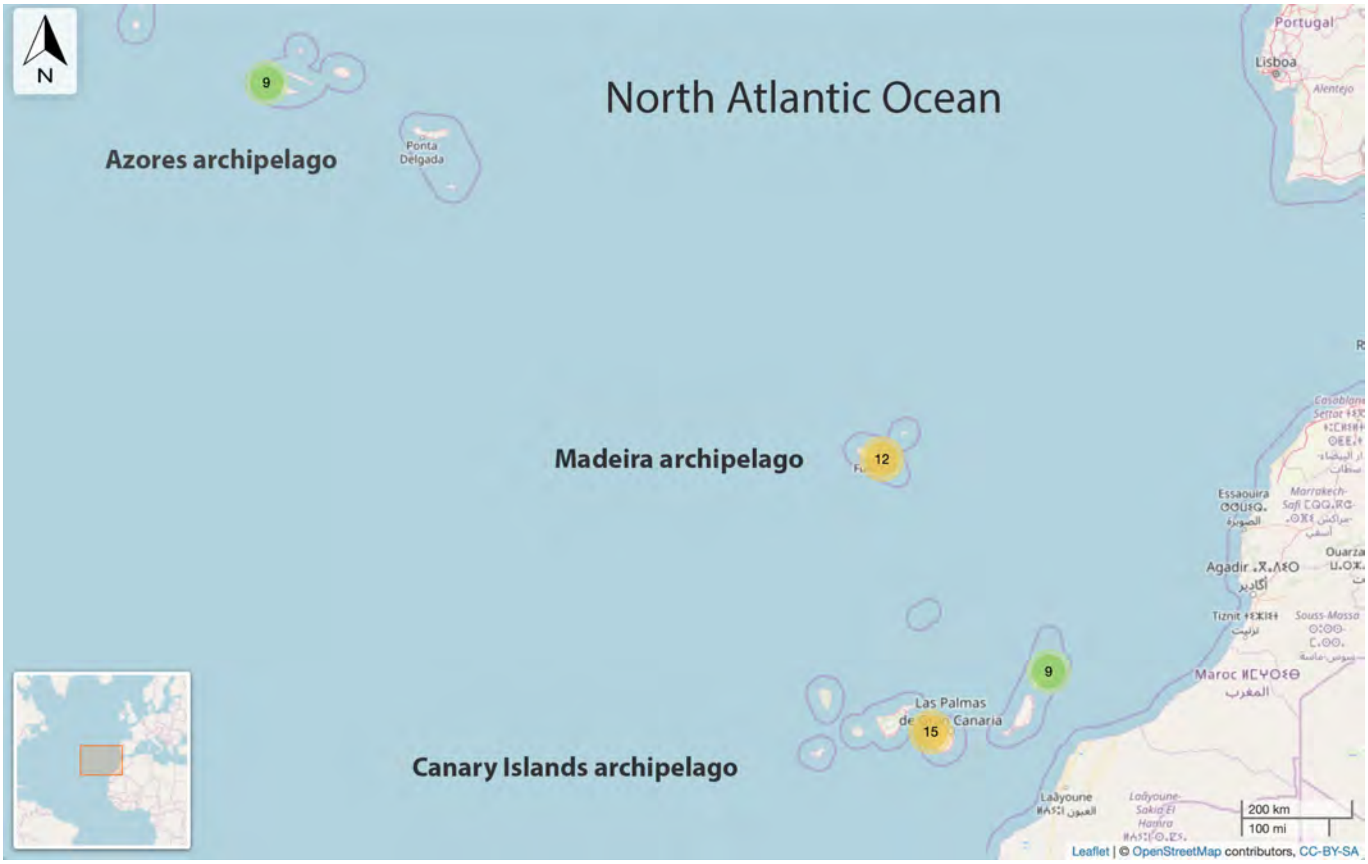

Fig. 1. Study area. The numbers inside the circles show the number of samples collected at each site.

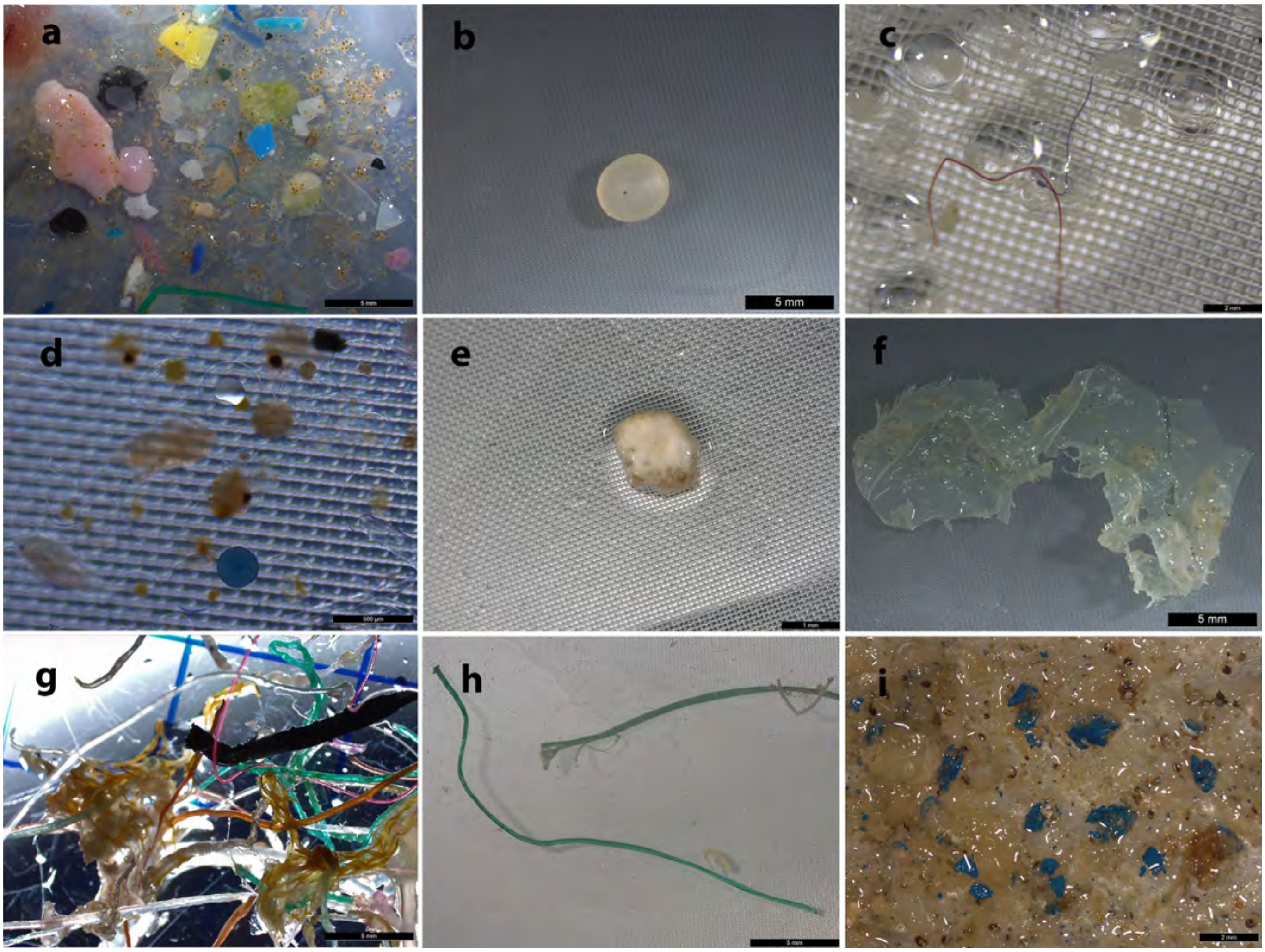

Fig. 2. Types of debris found. a) Irregular fragments (Fragments), scale bar = 5 mm. b) Industrial pellets (Pellets), scale bar = 5 mm. c) Fibres, scale bar = 2 mm d) Microbeads, scale bar = 500 µm. e) EPS and XPS (Foams), scale bar = 1 mm. f) Films, scale bar = 5 mm. g, h) Fishing lines (Lines), scale bar = 5 mm. i) Paint (Other), scale bar = 2 mm.

aluminium foil and tar (Other) (Fig. 2). Since FTIR was not available to identify the type of particles in the category fibres are included synthetic, semi-synthetic and natural.

During the entire process in the laboratory cotton lab coats were worn and all materials were carefully rinsed with bidistilled water to prevent contamination of the samples. A petri dish with clean 50 µm mesh was placed near the stereomicroscope during the visual inspection as contamination control. No contamination was found in any of the controls.

Zooplankton neuston samples were separated in 200–500; 500–1000 and > 1000 µm fraction size. Then, an aliquot of 10 or 20 ml, depending on plankton concentration, were scanned in a high resolution scan (Epson V800 Pro) and were counted and classified in large taxonomic groups using Zooprocess software V7.30 and ECOTAXA V2.0 (Picheral et al., 2017), as described in the protocol by Herrera et al. (2019a)

The microplastics and zooplankton (in number of units) collected were divided by the total area of filtered water and the concentration was expressed in items/km^{2}. The concentration was expressed in items/m^{3} only for the Azores' samples.

2.3. Statistical analysis

The data were analyzed and plotted using R statistical program V3.5.3 (R Core Team, 2019). To confirm normality, microplastics and zooplankton abundance data were analyzed by the Shapiro Wilk test and the homoscedasticity of the residuals was assessed graphically. Microplastics and zooplankton data were not normal and statistical differences between areas were tested using Kruskal-Wallis test and Conover posthoc test.

3. Results

3.1. Microplastics and zooplankton abundance

The maximum values of microplastics (items/km^{2}) were 1,007,872 in the Canary Islands, 467,259 in the Azores and 124,190 in Madeira (Table 2). However, no significant differences were found between the abundances of microplastics (items/km^{2}) among the archipelagos (p-value = 0.35). The mean values found at each locality expressed per km^{2} are summarized in Table 1 and Figs. 4a, 4b, 4c, 4d, 4e.

If we consider the values obtained in each locality, the maximum abundance found was in Las Canteras (1,007,872 items/km^{2}) and the minimum in Los Gigantes (15,482 items/km^{2}) both in the Canary archipelago (Figs. 3a and 4b).

Regarding the differences between localities within each archipelago, differences were only observed in the Canary Islands archipelago, being the values in Las Canteras significantly higher than in San Andres,

Table 1
Mean abundance of microplastics and zooplankton, and ratio of items of microplastics/number of zooplankton at each sampling location.

Location	Archipelago	Micro (items/km^2) Mean ± SD	Zoo (ind/km^2) Mean ± SD ($\times 10^6$)	Micro/Zoo items ratio
Lambra	Canary Islands	153,304 ± 95,348	5.7 ± 2.2	0.032
Arrecife	Canary Islands	157,102 ± 96,840	5.1 ± 1.9	0.030
Famara	Canary Islands	68,020 ± 75,654	38.0 ± 31.2	0.002
Taliarte	Canary Islands	154,570 ± 9217	1.4 ± 1.1	0.147
Las Canteras	Canary Islands	894,069 ± 98,951	15.7 ± 13.1	0.08
Gando	Canary Islands	125,949 ± 61,630	22.6 ± 18.4	0.008
San Andres	Canary Islands	21,326 ± 6281	3.1 ± 0.9	0.007
Los Gigantes	Canary Islands	27,593 ± 8895	14.4 ± 4.1	0.002
Caniçal	Madeira	87,538 ± 12,223	5.3 ± 4.0	0.028
Funchal	Madeira	40,054 ± 4711	9.5 ± 12.5	0.013
Desertas	Madeira	66,568 ± 19,379	7.3 ± 4.8	0.021
Caniço	Madeira	84,343 ± 39,828	5.1 ± 3.2	0.024
Praia do Norte	Azores	77,223 ± 40,279	140.7 ± 75.2	0.0007
Almoxarife	Azores	143,858 ± 143,033	95.0 ± 32.4	0.002
Porto Pim	Azores	300,352 ± 164,345	177.9 ± 98.7	0.002

Los Gigantes, and Famara as shown in Fig. 3a.

The maximum zooplankton abundance found were 288.9×10^6 ind/km^2 in Porto Pim, Azores; 73.4×10^6 ind/km^2 in Famara, Canary Islands; and 24×10^6 ind/km^2 in Funchal, Madeira. Significant differences in zooplankton abundance were observed between the Azores and Madeira (p-value = 7.4×10^{-7}) and between the Azores and the Canary Islands (p-value = 3.3×10^{-6}). The mean abundances found in each locality expressed per km^2 are summarized in Table 1. Within the Canary Island archipelago, in Famara, there was significantly higher abundance of zooplankton than in Taliarte and San Andres (p-values < 0.05). However, within the archipelagos of Madeira and Azores no significant differences were observed between the locations (p-values > 0.05)(Fig. 3b).

3.2. *Composition of debris and zooplankton*

In the samples collected in the Canary Islands and Azores archipelagos, 100% of the debris were microplastics and fibres (synthetic, semi-synthetic or natural). In the Madeira archipelago, on the other hand, 16% were other types of debris. Of the total microplastics collected in the Canary Islands 57.3% were fragments, 27.4% fibres, 9.9% lines and 5.3% films; in the Azores archipelago 54% were fibres, 34.9% fragments, 6.3% lines and 4.8% films; while in Madeira, from total debris 47.5% were fragments, 30% fibres, 4.6% styrofoam, 0.5% films, and 16.8% were other debris such as glass, paint, aluminium foil and tar (Fig. 5).

Regarding particle size, in the Canary Islands 50.6% were between 0.2 and 1 mm and the rest between 1 and 5 mm in size; in Madeira 39.4% of the particles had a size between 1 and 5 mm and the rest in the fraction between 0.2 and 1 mm; while in the Azores, only 17.5% of the particles were of the fraction of 1–5 mm, being 82.5% of a size between 0.2 and 1 mm (Fig. 5).

Neustonic zooplankton were classified into large taxonomic groups, in terms of abundance copepods were the dominant group, and the other major group were fish eggs. In the Canary Islands, the percentage of each group was 85% copepods, 12.5% eggs, 1% appendicularia, 0.5% salpidae and within the remaining 1% were found amphipods, annelids, chaetognats, decapods and euphausiids. Also in the Azores, the most abundant group were copepods with 44%, eggs 29.5%, cirripedia larvae 17.2% and ostracods 9.4% (Fig. 6b). In contrast, the neustonic zooplankton collected in Madeira were 60% eggs, 38.1% copepods, 1.2% appendicularia, and the remaining 1% were composed by annelids, decapods, salpids and chaetognats (Fig. 6c).

3.3. *Ratio microplastics /zooplankton*

The average ratio of microplastics /zooplankton(Micro/Zoo) in each of the archipelagos was 0.032 in the Canary Islands, 0.021 in Madeira and 0.002 in the Azores (Table 2). The mean values obtained in each locality are shown in Table 1. The highest Micro/Zoo ratios were found in the Canary Islands, in the localities of Taliarte (0.22), Las Canteras (0.1) and Lambra (0.06) (Fig. 3c). In Madeira, maximum values of 0.06 were found in Caniçal (Fig. 3c). In the Azores archipelago, the maximum values reached were 0.005 in Porto Pim and Almoxarife (Fig. 3c). The Micro/Zoo ratio was significantly lower in the Azores than in the Canary Islands and Madeira (p-values < 0.05). Within each archipelagos, significant differences were only observed in the Canary Islands, with significantly higher MP/Zoo ratios in Taliarte and Las Canteras than in Famara and Los Gigantes (p-values < 0.05)(Fig. 3c).

The ratio of microplastics/zooplankton in dry weight was estimated only in the samples from Las Canteras for the fraction > 1 mm, as they were the only ones that contained enough microplastics to do that estimation. In the 3 samples collected within that fraction, the Micro/Zoo dry weight ratio was 2.70, 2.67 and 0.50 respectively, being the average value 2.0 ± 1.3.

4. Discussion

The mean values of MPs in items per km^2 are in the range of those found in other areas of the ocean (see review in Table 2). The maximum values found in Las Canteras are similar to those reported in areas of high accumulations such as the North Pacific Central Gyre (Moore et al., 2001) and the Mediterranean Sea (Collignon et al., 2012; Ruiz-Orejón et al., 2016); but lower than those reported by Law et al. (2014) in the Eastern Pacific accumulation zone, and Suaria et al. (2016) and Van Der Hal et al. (2017) also for the Mediterranean.

High concentrations of microplastics were found in the three archipelagos, especially in the localities of Las Canteras in the Canary Islands, and Porto Pim in the Azores, both located in a semi-enclosed bays, acting as retention zones. Other authors have also reported high abundances of microplastics in bays of Tokyo and Brazil (Cheung et al., 2018; Figueiredo et al., 2018).

Las Canteras' sampling area is located within El Confital bay on the northeast coast of Gran Canaria. According to the circulation model proposed in the study carried out by Mcknight (2016) in El Confital Bay, N and NNW wind scenarios shows a recirculation pattern in the eastern-central of the bay. In contrast, with the NE and NNE winds -the predominant winds in the area- it shows a circulation pattern towards the west but intensified in the northeast cape, where the flux is directed towards the bay in southwest direction.

Mcknight (2016) analyzed the relationship between near-shore surface circulation and marine debris deposition on the beach, but there are no studies in the region that relate surface circulation to floating debris. It is probable that the recirculation pattern observed under N

Table 2

Bibliographic search in Web of Science by terms *debris and *neustonic from 1900 to 2019 showed 48 results. From these results, we selected the articles that report data of neustonic microplastics or debris in the oceans.

Sampling area	Net Mesh size μm	Mean MP Items/km^2	Max MP Items/km^2	Mean MP Items/m^3	Max MP Items/m^3	MP/zoo Ratio items	Reference	Year
Chabahar Bay, Gulf of Oman	Neuston 333			0.49	1.14		Aliabad et al. (2019)	
Black Sea	WP2 200			0.0012			Aytan et al. (2016)	
Bornholm Basin, Baltic Sea	Bongo 150			0.21	0.28		Beer et al. (2018)	
Pearl River estuary, Hong Kong waters	Manta 333	334,780	1,675,982	3.97	29697		Cheung et al. (2018)	
North Western Mediterranean Sea	Manta 333	116,000	892,000				Collignon et al. (2012)	
Bay of Calvi, Mediterranean Sea	Manta 333	62,000	688,000			0.0006	Collignon et al. (2014)	
Sardinian Sea, Western Mediterranean	Manta 500			0.15	0.35		De Lucia et al. (2014)	
Northern Gulf of Mexico	Neuston 335			13	21.6	0.0058	Di Mauro et al. (2017)	
Northeast Bering Sea, Pacific Ocean	Sameoto 505			0.017-0.072	0.072		Doyle et al. (2011)	
Southern California, Pacific Ocean	Manta 505			0.004-0.19	0.19		Doyle et al. (2011)	
South Pacific subtropical gyre	Manta 333	26,988	396,342				Eriksen et al. (2013)	
Western Mediterranean Sea	Manta 333	129,682	420,000				Faure et al. (2015)	
Guanabara Bay, Southeastern Brazil	Neuston 64	900,000	1,900,000	4.8	11		Figueiredo et al. (2018)	
Pelagos Sanctuary, Western Mediterranean Sea	Mantan 333	82,000	264,000				Fossi et al. (2017)	
Bay of Brest, France	Manta 335			0.24	1.43		Frère et al. (2017)	
Portuguese coastal waters, Aveiro	Neuston 280–335			0.002		0.04	Frias et al. (2014)	
Portuguese coastal waters, Lisboa	Neuston 280–335			0.033		0.12	Frias et al. (2014)	
Portuguese coastal waters, Costa Vicentina	Neuston 280–335			0.036		0.14	Frias et al. (2014)	
Portuguese coastal waters, Algarve	Neuston 280–335			0.014		0.005	Frias et al. (2014)	
Spanish northwest coast	Manta 335	34,000					Gago et al. (2015)	
Spanish northwest coast	Manta 335	176,000					Gago et al. (2015)	
Stockholm Archipelago, Baltic Sea	Manta 335	110,000	618,000	1.37	7.73		Gewert et al. (2017)	
Southern California Current, Pacific Ocean	Manta 505			0.011			Gilfillan et al. (2009)	
Southern California Current, Pacific Ocean	Manta 505			0.033			Gilfillan et al. (2009)	
Southern California Current, Pacific Ocean	Manta 505			0.016			Gilfillan et al. (2009)	
East Asian Seas, Japan	Neuston 350		172,0000	3.74	491		Isobe et al. (2015)	
Southern Ocean, Antartica	Manta 350	100,000		0.031	0.099		Isobe et al. (2017)	
Western Tropical Atlantic, Abrolhos	Manta 300			0.04			Ivar do Sul et al. (2014)	
Western Tropical Atlantic, Fernando de Noronha	Manta 300			0.015			Ivar do Sul et al. (2014)	
Western Tropical Atlantic, Trinidade	Manta 300			0.025	0.13		Ivar do Sul et al. (2014)	
Western Tropical Atlantic Ocean	Manta 300			0.03			Ivar do Sul et al. (2014)	
Atlantic Ocean	Pump 250			1.15	8.5		Kanhai et al. (2017)	
South East Sea of Korea	Manta 330			1.92-5.51			Kang et al. (2015)	
South East Sea of Korea	Manta 330			2.30-38.77			Kang et al. (2015)	
North Western Australia, Indian Ocean	Manta 355			0.01-0.41			Kroon et al. (2018)	
North Western Australia, Indian Ocean	Plankton			0.00-0.09			Kroon et al. (2018)	
Santa Monica Bay, California	Manta 333			3.92			Lattin et al. (2004)	
Eastern Pacific Ocean (accumulation zone)	Neuston 333	156,800	12,340,000				Law et al. (2014)	
Eastern Pacific Ocean (outside)	Neuston 333	1,864					Law et al. (2014)	
Goiana Estuary, Northeast coast of Brazil	Plankton 300			0.26		0.0019	Lima et al. (2014)	
Northeast Altantic Ocean	Pump 250			2.46	22.5		Lusher et al. (2014)	
Artic waters, Norway	Manta 333	28,000		0.34	1.31		Lusher et al. (2015)	
Artic waters, Norway	Pump 250			2.68	11.5		Lusher et al. (2015)	
North-East Altantic	Manta 333	36,623	375,854	0.15	1.5		Maes et al. (2017)	
North Pacific Central Gyre	Manta 330	334,271	969,777	2.23		0.1819	Moore et al. (2001)	
Southern California coastal waters	Manta 333			7.25			Moore et al. (2002)	
Mediterranean Sea, near coast	Manta 333	158,000	578,000			0.03	Pedrotti et al. (2016)	
Mediterranean Sea, > 10 km from coast	Manta 333	370,000				0.006	Pedrotti et al. (2016)	
Central and Western Mediterranean Sea	Manta 333	147,500	1,164,403				Ruiz-Orejón et al. (2016)	
Southern coast Korea	Manta 333			43			Song et al. (2014)	
Mediterranean Sea	Neuston 200	400,000	4,520,000	1	11.3		Suaria et al. (2016)	
Israeli Mediterranean coast	Manta 333	1,518,384	64,812,600	7.68	324		Van Der Hal et al. (2017)	
Mediterranean Sea	Manta 200	24,3853					Cózar et al. (2015)	
North Atlantic Ocean, Azores	Manta 200	173,811	467,260	0.44	1.19	0.002	Present work	
North Atlantic Ocean, Madeira	Manta 200	69,626	124,190			0.021	Present work	
North Atlantic Ocean, Canary Islands	Manta 200	194,951	1,007,872			0.032	Present work	

and NNW wind conditions may affect the transport of floating debris, determining the accumulation in the central areas, which would explain the high values found at Las Canteras. Further studies are needed to understand the effect of coastal hydrodynamics on the accumulation of neustonic microplastics.

As can be observed in Table 1, there is a great variability in the concentrations found in the different sampling areas, even between nearby localities such as Las Canteras and San Andres. Although significant differences were observed between archipelagos, both in microplastics and zooplankton abundance, it is probable that these differences are due to the fact that sampling was opportunistic, at different times and with different methods. Other authors have found that there are variability in the estimations of microplastics according to the methodology used (Barrows et al., 2017; Eriksen et al., 2018; Green et al., 2018), so we should be cautious when making this type of comparison. Therefore, it is necessary to carry out a specific study in the area in order to determine the spatial variability.

Our data show for the first time that this region is an area highly polluted by microplastics and other debris. The situation of the islands in the flow of the descending branches of the Gulf Stream is probably making them especially vulnerable to microplastic pollution, as demonstrated by studies on beaches in the region (Álvarez-Hernández et al., 2019; Baztan et al., 2014; Gestoso et al., 2019; Herrera et al., 2018) and marine organisms (Herrera et al., 2019b; Pham et al., 2017;

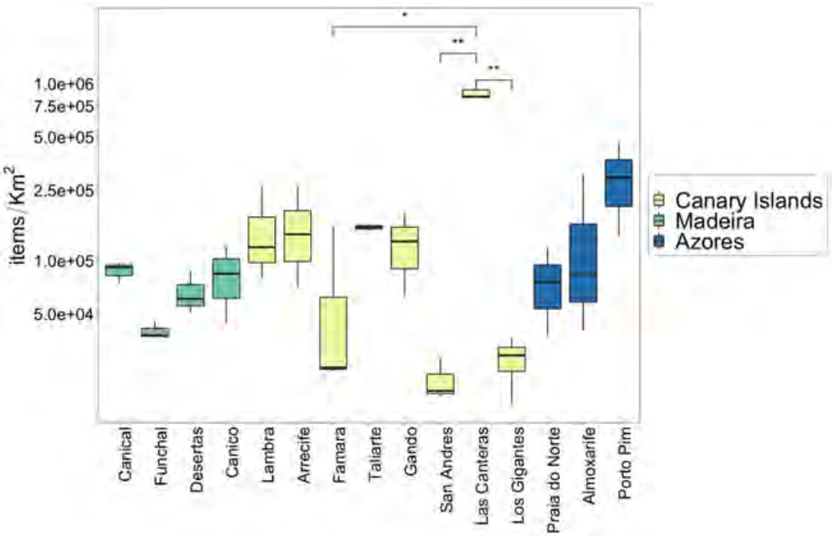

Fig. 3a. Abundance of microplastics (0.2–5 mm) in items by km^2 at each location. The central thick line of each box designates the median, the box height shows the interquartile range, and the whiskers indicate the lowest and the highest values. Significant differences between locations within each archipelago are shown ** ($p < 0.05$), * ($p < 0.01$).

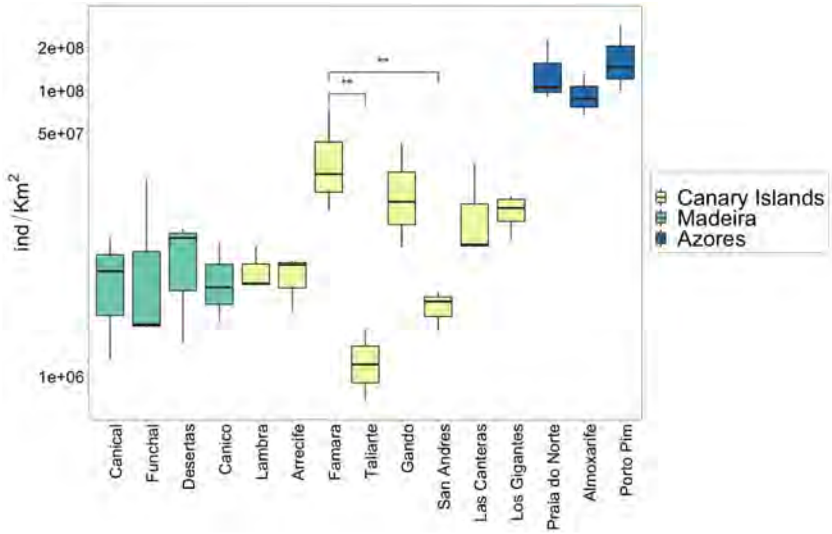

Fig. 3b. Neustonic zooplankton in individuals by km^2 at each location. Y axis was log2 transformed in order to improve data visualization. Significant differences between locations within each archipelago are shown ** ($p < 0.05$), * ($p < 0.01$).

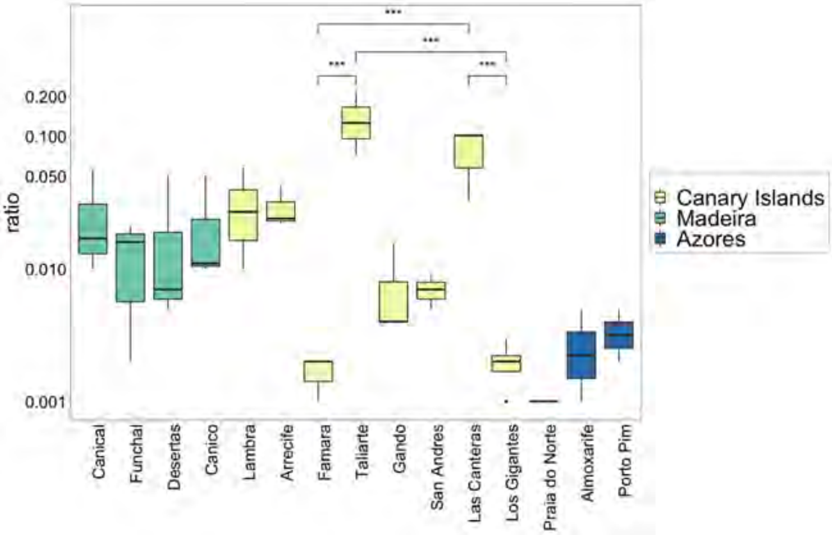

Fig. 3c. Ratio Microplastics/Zooplankton abundance. Significant differences between locations within each archipelago are shown ** ($p < 0.05$), * ($p < 0.01$).

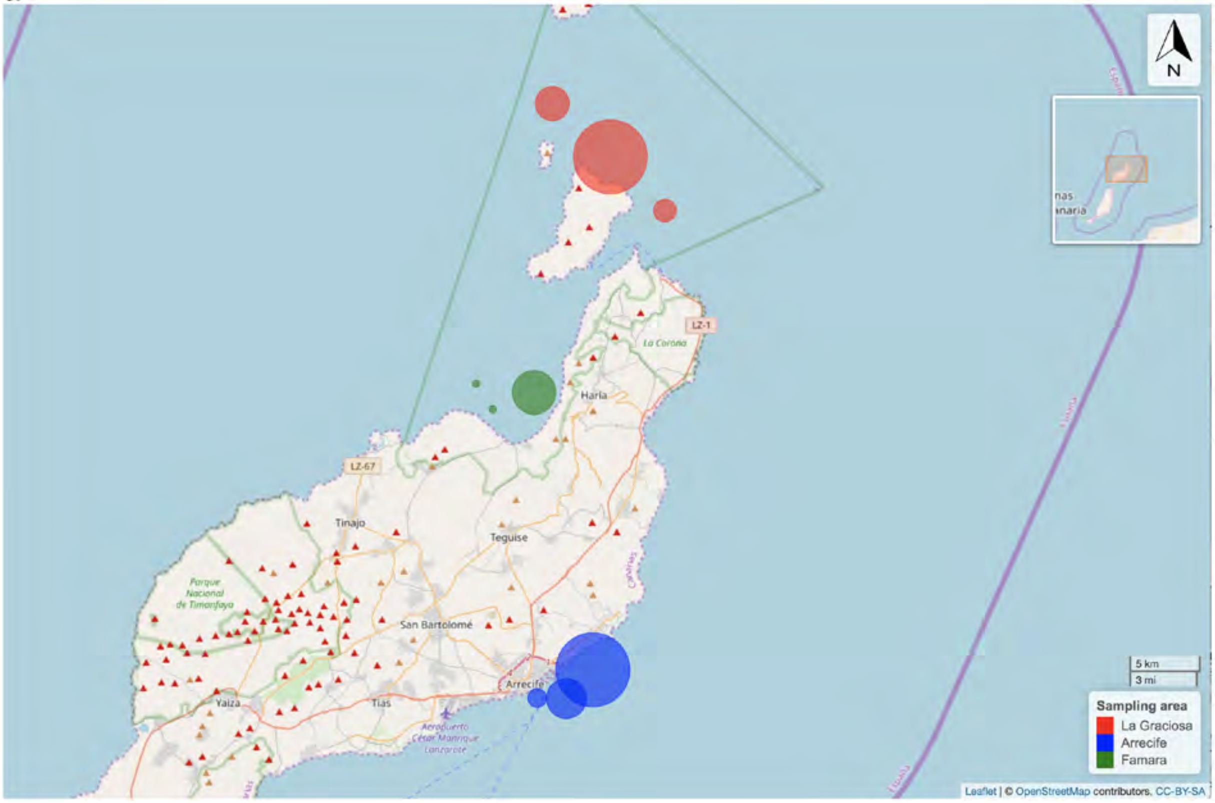

Fig. 4a. Abundance of microplastics in items/km^2 in coastal waters of Lanzarote and La Graciosa Islands, Canary Islands archipelago.

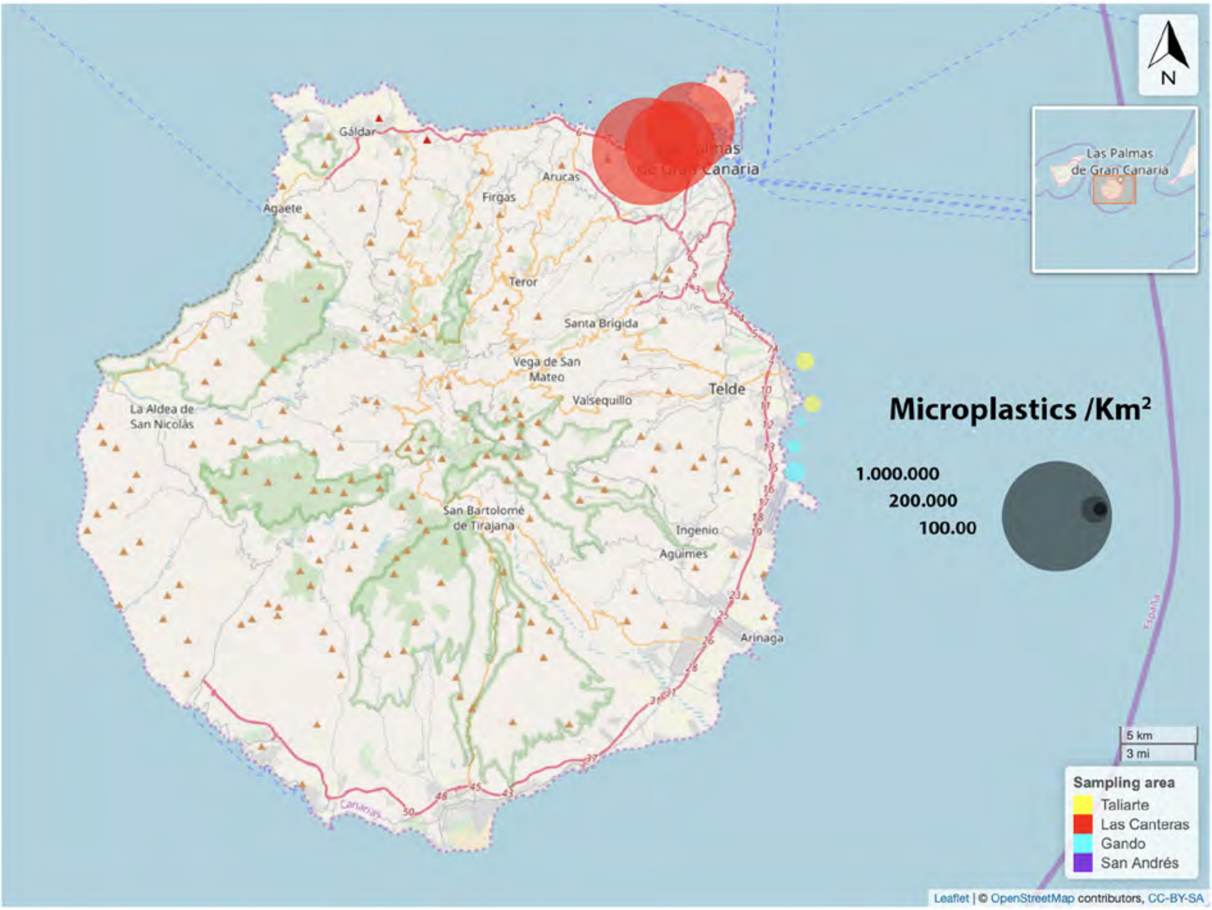

Fig. 4b. Abundance of microplastics in items/km^2 in coastal waters of Gran Canaria Island, Canary Islands archipelago.

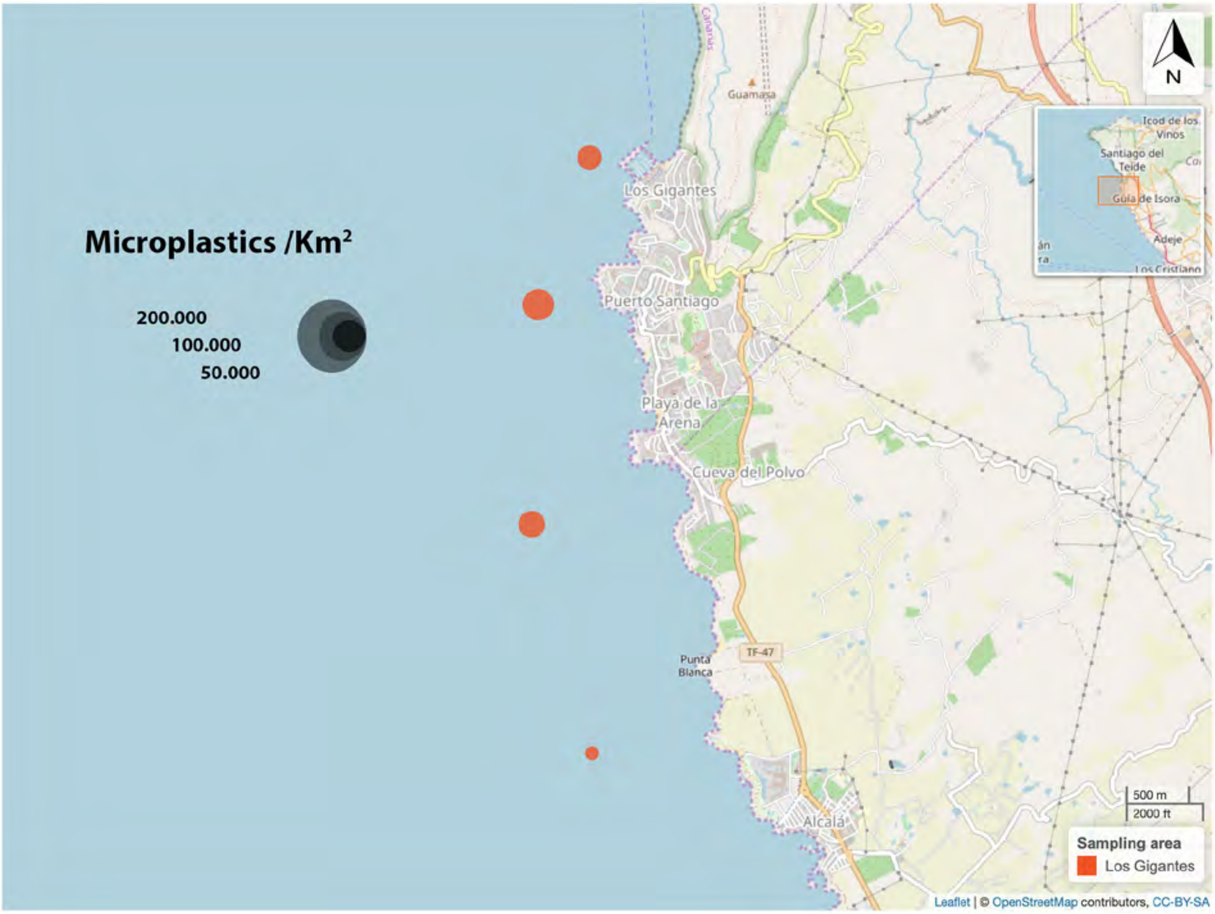

Fig. 4c. Abundance of microplastics in items/km^2 in coastal waters of Tenerife Island, Canary Islands archipelago.

Rodríguez et al., 2012).

Regarding the categories, most of the microplastics were fragments and fibres, these results agree with those reported worldwide (Aliabad et al., 2019; Cózar et al., 2015; Di Mauro et al., 2017; Eriksen et al., 2013; Faure et al., 2015; Figueiredo et al., 2018; Gewert et al., 2017; Suaria et al., 2016), and with the types of microplastics found in the stomach of Atlantic chub mackerel (*Scomber colias*) collected in Canary Islands waters (Herrera et al., 2019b) and juvenile loggerhead turtles (Pham et al., 2017). However, the percentages found in sub-surface waters off the beaches of Famara, Lambra and Las Canteras do not correspond to those found in high tide line sediments. In Famara almost 44.3% of the microplastic samples collected from beaches were composed of pellets, however in the sub-surface water samples no pellets were found. Something similar occurs in Lambra that presented a 35.6% of tar in the sand samples, but this type of waste did not appear in the samples collected with the manta net. These results suggest that the pattern of accumulation of different types of microplastics at the tide line differs from that at the sea surface. This could be due to the fact that the different types, either by their shape or composition, are deposited in different ways in the sand.

In the present study, samples showed a high percentage of microplastics with respect to zooplankton in abundance, especially in some areas such as Taliarte, Las Canteras and Lambra. Microplastics reached values of 22% of the zooplankton samples in Taliarte, this could explain the high incidence of microplastics in the planktivorous fish Atlantic chub mackerel (*Scomber colias*) collected in the Canary Islands according to the study carry out by Herrera et al. (2019b). This Micro/Zoo ratio in abundance is similar to the ones found by Moore et al. (2001) in the North Pacific Central Gyre and Frias et al. (2014) on the Portuguese coast, and much higher than that reported by other authors (see Table 2).

In addition, the dry weight ratio for the 1–5 mm fraction in the Las Canteras area showed twice times much microplastics as zooplankton. Collignon et al. (2012) found an average weight ratio of 0.5 and Moore et al. (2001) found 6 times more plastic than zooplankton in the area near the accumulation of the North Pacific Subtropical Gyre. Although the ratio is higher, Moore et al. (2001) included the fraction greater than 5 mm, whereas in the present study the ratio of 2 was found taking into account only the fraction of 1–5 mm.

This high percentage of microplastics in the zooplankton samples could have a great impact on the health of marine organisms, either because of the physical danger of ingestion, the associated chemical contaminants or the false sense of satiation that could affect the intake of nutrients, especially in large filter feeders species. Fossi et al. (2017) demonstrated the overlap of zones of microplastic accumulation with the feeding areas of fin whales in the Pelagos Sanctuary in the Mediterranean, highlighting the high intake risk for marine biota.

One of the main concerns of the scientific community is the effects that microplastics can have on marine organisms and the food chain. Many studies have demonstrated the ingestion of microplastics in invertebrates, fish, seabirds and cetaceans. However, the risk associated with this ingestion is still unknown. On the other hand, microplastics have been shown to possess various types of associated chemical contaminants (Camacho et al., 2019; Endo et al., 2005; Hirai et al., 2011; Ogata et al., 2009; Rios et al., 2007) and these could affect the health of organisms (Derraik, 2002; Rochman et al., 2013; Teuten et al., 2009).

Also, the high microplastics-zooplankton ratio found in this study demonstrates the potential risk it may have for biota and marine ecosystems, especially if we consider that high levels of POP's and emerging chemical pollutants have already been reported by Camacho et al.

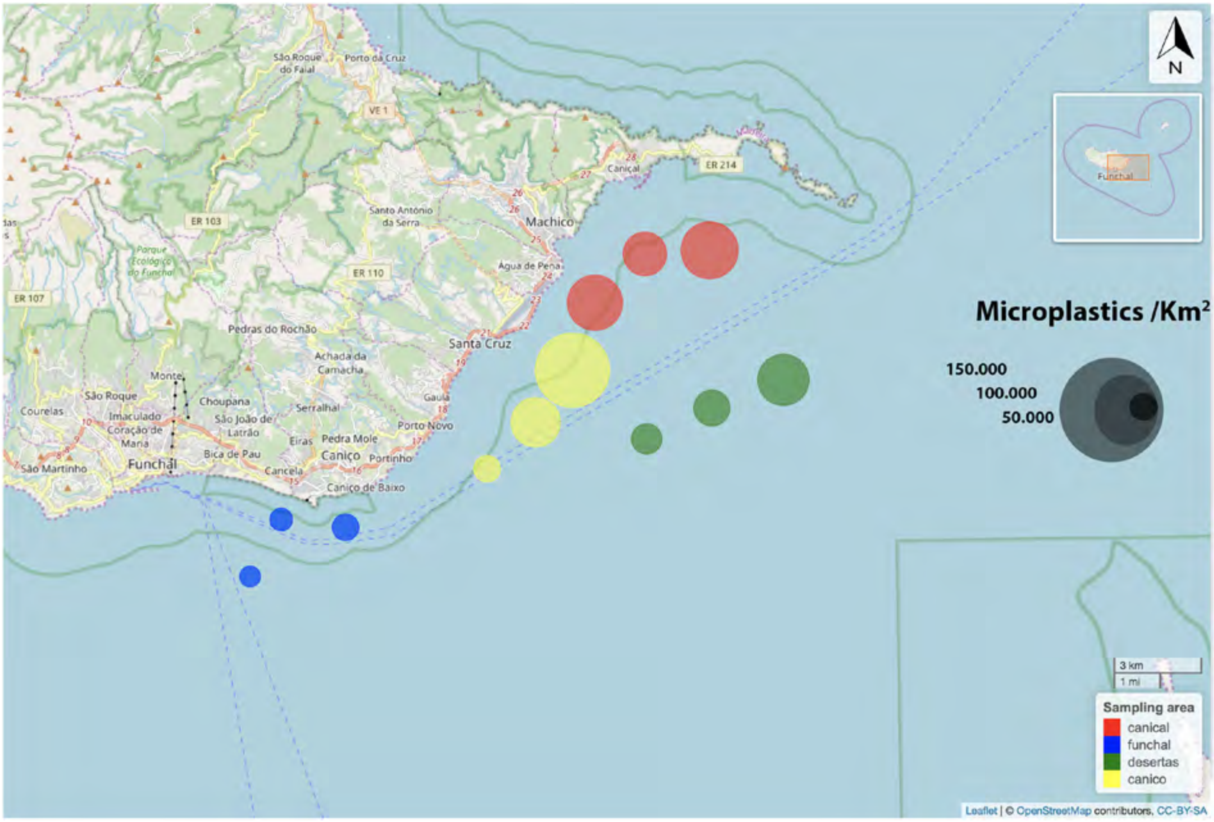

Fig. 4d. Abundance of microplastics in items/km^2 in coastal waters of Madeira Island, Madeira archipelago.

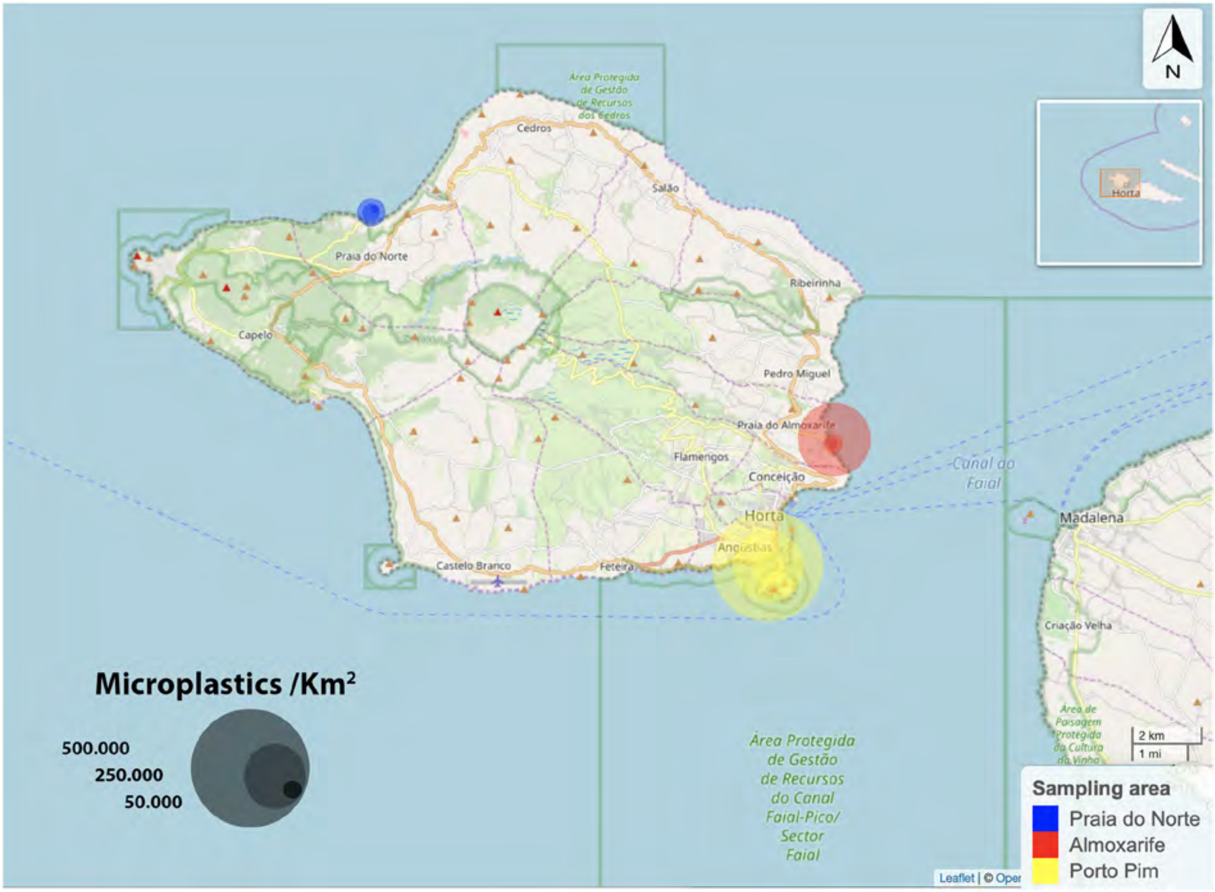

Fig. 4e. Abundance of microplastics in items/km^2 in coastal waters of Faial Island, Azores archipelago.

Fig. 5. Percentage of type and size of debris found at each archipelago. (a) Canary Islands archipelago. (b) Madeira archipelago. (c) Azores archipelago. Category “Other" include glass, paint, aluminium foil and tar.

(2019) in microplastic samples collected in the Canary Islands. The waters around Macaronesia are important feeding grounds for some large filter feeders, such as the whale shark (*Rhincodon typus*), the basking shark (*Cetorhinus maximus*), several species of manta rays of the genus *Mobula* (*M. tarapacana*, *M. mobular*, *M. birostris*); and filter whales of the genus *Balaenoptera* (*B. edeni*, *B. bryde*, *B. physalus*, *B. borealis*, *B. musculus*) (Carrillo et al., 2010; Das and Afonso, 2017; Espino et al., 2014; Prieto et al., 2014, 2017; Silva et al., 2014; Sobral and Afonso, 2014). According to our results, these species among others have a high potential risk of ingestion of microplastics and associated chemical contaminants.

5. Conclusions

1 — High levels of contamination by neustonic microplastics (0.2–5 mm) were found in various areas of Macaronesia, reaching

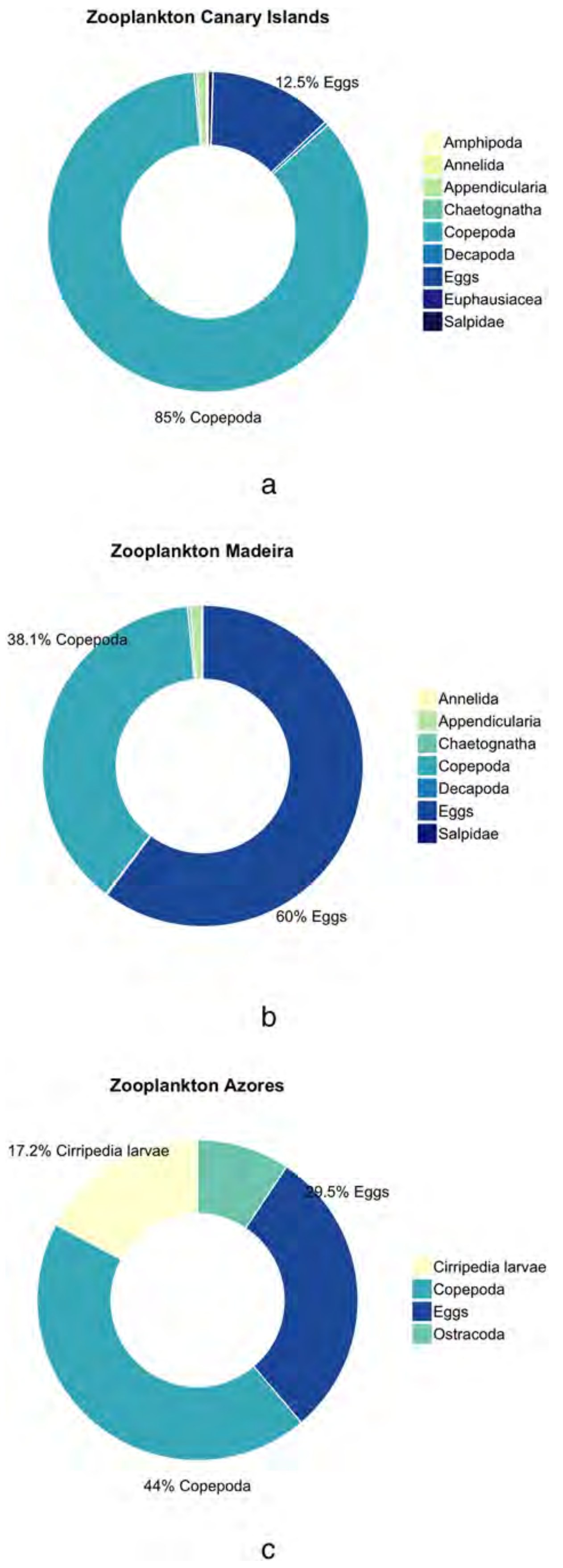

Fig. 6. Percentage of taxonomic groups from total neustonic zooplankton collected at each archipelago. (a) Canary Islands archipelago. (b) Madeira archipelago. (c) Azores archipelago.

values of more than 1 million particles per square kilometre.

2 — The microplastics-zooplankton abundance ratio was very variable in the different zones, reaching values of 0.22.

3 — We found twice as much microplastics as zooplankton in dry weight for the 1–5 mm fraction in the area of greatest accumulation in Las Canteras.

4 — It is necessary to carry out more studies of floating microplastics abundance in order to understand the circulation and accumulation patterns in the Macaronesian region.

5 — In addition, studies on the abundance of neustonic microplastics and zooplankton and their impact at different levels of the food web are needed to assess possible risks to marine organisms.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2020.110999.

CRediT authorship contribution statement

A. Herrera: Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **E. Raymond:** Data curation, Investigation, Writing - review & editing. **I. Martínez:** Data curation, Writing - review & editing. **S. Álvarez:** Data curation, Writing - review & editing. **J. Canning-Clode:** Data curation, Writing - review & editing. **I. Gestoso:** Data curation, Writing - review & editing. **C.K. Pham:** Data curation, Writing - review & editing. **N. Ríos:** Data curation, Writing - review & editing. **Y. Rodríguez:** Data curation, Writing - review & editing. **M. Gómez:** Data curation, Writing - review & editing.

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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