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Comparison between the traditional Manta net and an innovative device for microplastic sampling in surface marine waters

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A B S T R A C T

Manta nets are commonly used for microplastics sampling although a number of limitations have emerged. In this study we compare the manta net to an innovative microplastic sampler, referred to as MuMi, registered as utility model. The results highlight the large variability that can exist in the outcomes of the different studies due to the lack of harmonization between methods and the differing factors such as sampling mesh size, representativeness or reproducibility of the sampling volumes. Control over the filtered volume is an issue to be improved in trawl sampling methods, while in the MuMi sampler the control over the sampling depth could be improved. Still, MuMi represents a highly advantageous sampling system in terms of ease of operation, lower cost, smaller microplastics target size and greater precision, all while maintaining the representativeness of the collected samples.

1. Introduction

One of the problems facing mankind today is the excessive amount of plastic that ends up in the ocean every year: at least 14 million tons according to a recent report (International Union for Conservation of Nature and Natural Resources (IUCN), 2021). Once in the marine environment, plastic moves and accumulates based on both physical oceanographic and biological factors, so there is evidence of marine litter throughout the seas and oceans, from surface water to deep-sea sediments (van Sebille et al., 2020). The persistence of plastics in nature can lead to serious risks for humans and wildlife, resulting in ecosystem changes, exposure to chemicals, which are either present in the composition of these plastics or have been adsorbed onto them in the marine environment, and to lethal and sub-lethal effects due to entanglement with plastic elements by marine wildlife or ingestion (Rochman, 2015).

The monitoring of microplastics in the different environmental compartments is key to know the state and behaviour of these synthetic particles in the environment and therefore to be able to adopt consequent management measures according to their distribution and abundance (Lusher et al., 2021). The sampling methods chosen should fit the objectives of the desired monitoring programme, as well as follow recommended guidelines or harmonized methods (Martin et al., 2022). An equally important issue highlighted by Lusher et al. (2021) is that these methods cannot be static but need to be flexible enough to incorporate improvements as they are developed. Under these premises, guidelines for the harmonization of microplastic reporting have been written in order to, without recommending one method over another, ensure that a set of basic information is provided, such as the mesh size and its aperture, so that results can be as comparable as possible (Cheshire and Adler, 2009; Galgani et al., 2013). In an effort to harmonise methodologies and improve the comparability of national and international monitoring programmes, the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 2019) provided a series of recommendations on methods for developing the best monitoring strategies according to the objectives pursued in the four main environmental compartments (i.e. coastline, sea surface/water column, seabed and biota). Oceans are particularly difficult to monitor as they are areas of enormous surface and volume, in constant movement and affected by numerous physical, chemical and biological

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processes (Chester and Jickells, 2012; Kvale et al., 2020). In addition, if the intention with the monitoring programme is to detect small changes in abundance, or more precise trends, sampling will need to be correspondingly more comprehensive, requiring a greater number of samples. In this sense, opportunistic sampling, where microplastic monitoring is integrated into an existing research programme, can provide a cost-effective approach (GESAMP, 2019; Lusher et al., 2021). These reasons make sampling microplastics in the marine environment a challenge in development, for which numerous methods have been tested (Sönmez et al., 2022). Already a decade ago, Hidalgo-Ruz et al. (2012) published a review of the different methods for sampling microplastics in the environment, where for the specific case of aquatic samples, 33 studies were identified in which up to 5 different mesh sizes and various depths were used. In the same vein, Barrows (2017) reviewed the different existing methods for sampling microplastics in aquatic environments, differentiating between those that collect specific volumes of water that are filtered a posteriori (such as bottle grab samples or Niskin bottle samples) or the most extended net sampling surveys, concluding that a combination of methods is the optimal choice to achieve a more complete understanding of the distribution and abundance of microplastics in a given environment. As background in this field, we have carried out several microplastic monitoring tests in marine surface waters both from research vessels and from smaller, recreational vessels, and testing both continuous water pumping systems and collection methods using the rosette (Montoto-Martínez et al., 2020). Still, harmonization and standardization of survey methods to compare the results around the world remains a major challenge (Michida et al., 2019).

Among the diversity of sampling methods, the Manta trawl has been the predominant one for surface water sampling (GESAMP, 2019; Mai et al., 2018). This method has promoted the sampling of microplastics by different stakeholders, triggering monitoring campaigns by environmental institutions and organizations. However, despite its popularity, it has some disadvantages that could be misreporting microplastic abundance, such as inaccuracy in calculating the sampled volume due to water turbulence, or its inefficiency in recovering microplastics smaller than 300 μm due to the limitation of the mesh size (Eriksen et al., 2018; GESAMP, 2019; Mai et al., 2018; Montoto-Martínez et al., 2020). In addition to this, attributable in part to the limitation of net opening, the total amounts of buoyant microplastics may be underestimated by a factor of 1.04 to 30.0 (Kooi et al., 2016). Moreover, as Martin et al. (2022) pointed out, trawl sampling is impractical where there is high biomass or adverse weather conditions. In addition, the need to take into account the vertical distribution of microplastics, as well as how it may change with different flow and sampling conditions, to report concentration data for these particles is becoming increasingly apparent (Lenaker et al., 2019; Song et al., 2018), a field where recommendations for sampling microplastics in water and sediment from the same region (as a multi-matrix monitoring approach) have just been published (Martin et al., 2022).

The objective of this study was to compare the most widely used and globally accepted sampling method, albeit with its drawbacks, the Manta net, with an innovative microplastic sampling device, referred to as MuMi (its acronym in Spanish), specifically designed and manufactured to overcome some of these drawbacks. The MuMi sampler has been created by the University of Las Palmas de Gran Canaria, and protected as Utility Model (Montoto-Martínez et al., 2021a) and is presented in detail in the Material and methods section below. This manuscript is intended to elucidate the advantages and disadvantages of one and the other in order to refine their applicability.

2. Material and methods

2.1. Sampling area

The study area is located in the south of Tenerife, an island of the Canary Islands archipelago (Spain). The coastal strip in front of which the transects were carried out is heavily anthropized and influenced by the sun and beach tourism industry, with a large number of hotel, water supply and management infrastructure that result in a large census of discharges into the sea (Gobierno de Canarias - Consejería de Transición Ecológica, Lucha contra el Cambio Climático y la Planificación Territorial, 2017). In addition, the adjacent marine strip is classified as a Special Conservation Area ZEC ES7020017 Franja marina de Teno-Rasca (Ministerio de Medio Ambiente, y Medio Rural y Marino, 2011), especially due to the presence of cetaceans, with presence of resident species such as pilot whales (*Globicephala macrorhynchus*) and bottlenose dolphins (*Tursiops truncatus*) (Fig. 1). Linked to this fact, numerous whale watching companies and other recreational activities take place in this same area, so we consider that it is a location that requires and will benefit from monitoring in terms of the environmental quality of its waters, including microplastic contamination.

2.2. Sampling strategy

In general terms, the sampling strategy was designed, with the means available, to make a comparison between two microplastic sampling techniques in marine surface waters, trying to keep as many common variables as possible in order to discuss the differences found in the results, both at the level of reporting particle concentration and in terms of handling and operability.

Samples were collected during a cruise on-board Marhaba Catamaran on June 17th 2020. The navigation started on departure from Los Gigantes Harbour and was carried out in a southeasterly direction, sailing one mile away from the coast, covering a large part of the most anthropized coastline of the island. Sea conditions were optimal during the day, with all casts being made during daylight with Beaufort scale conditions between 0 and 2.

A total of six one mile transects (measured by GPS coordinates) were conducted at a speed of around three knots, keeping course parallel to the coast. In each of the transects, the two sampling methods to be compared, the Manta trawl and the MuMi device, were launched from the stern of the vessel (Fig. 2). They remained in the water for the same duration, approximately 20 min, simultaneously sweeping the sea surface.

2.2.1. Manta trawl

The Manta trawl used in this study was "built-in-house", using an aluminum frame with a rectangular mouth opening width 60 cm and height of 25 cm and a nylon net with a mesh size of 200 μm, that was attached to the frame. At the end of the net, a detachable cod-end with a mesh of 200 μm was placed using clamps. This piece was made from 3-mm thick grey polypropylene tubes with a length of 23 cm and a diameter of 11 cm.

Once positioned at the starting point of the transect, the Manta net was launched from the stern of the boat, and navigation began. Having reached the nautical mile (nm), the lines were pulled to retrieve the structure on board, where the net was rinsed with seawater jets, so that all the material trapped in the length of the net passed through the cod-end. Once the net was cleaned, the end of the tube was detached, and the contents were emptied into plastic bottles for subsequent filtering, digestion and analysis in the shore-based laboratories. The entire net and cod-end were thoroughly cleaned with seawater before being set out again for a new transect. The volume of water sampled by the Manta net was calculated according to the estimates of Karlsson et al. (2020), by multiplying the distance travelled (1 NM = 1852 m) by the area of the mouth of the Manta net (60 cm × 25 cm) and dividing by two, since it is assumed that the manta net moves up and down and remains semi-submerged on average.

2.2.2. The MuMi sampler

The MuMi sampler is a device that allows the sampling of

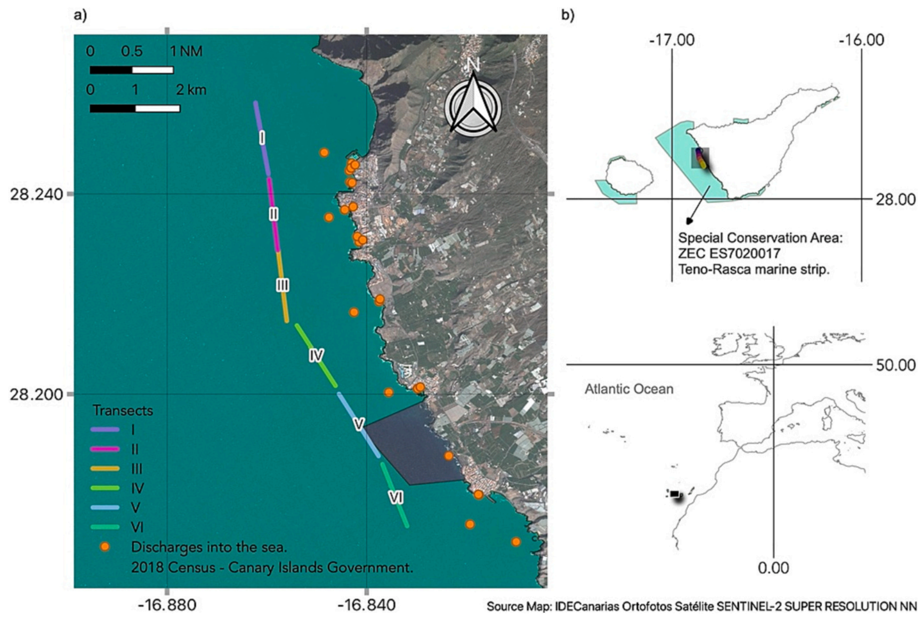

Fig. 1. a) Location map of the sampling area, in the South of Tenerife, Canary Islands (Spain). Each of the lines (I–VI) represents a one-mile transect. b) The coloured stripes in the sea delimit Special Conservation Areas. Specifically, the sampling was carried out in the ZEC ES7020017 Teno-Rasca marine strip. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

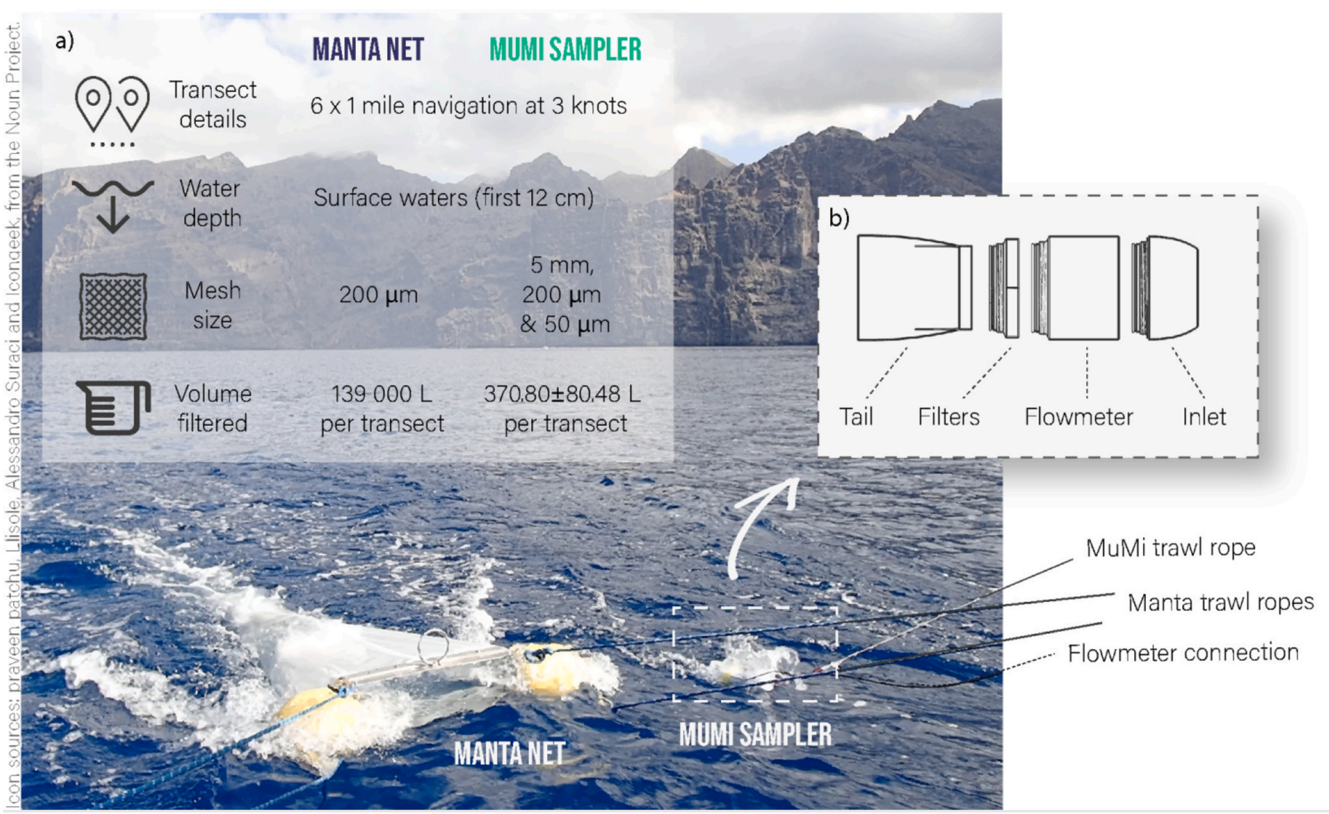

Fig. 2. View of the sampling arrangement of both systems tested: the Manta net and the MuMi sampler. a) Comparative table of the main sampling characteristics. b) Detailed diagram of the parts of the MuMi sampler, registered as Utility Model (20211000078).

microplastics present in aquatic environments. One of its main advantages in terms of sampling design is that it allows the use of unique filters for each sampling, easily interchanging them between transects. It is manufactured in Polylactic Acid (PLA) by means of 3D printing and it counts with an in-built flow meter which, by means of the connection cable and a display on board, allows the volume of filtered water to be known and displayed directly from the vessel, which is another very valuable feature.

As can be seen in detail in Fig. 2b, MuMi has a rounded hydrodynamic entrance head and an opening whose morphology facilitates the conduction of the water towards the interior of the device, where the filters are located. After the inlet, all the water volume to be sampled passes through an annular ring that houses the flow meter. The water flow then passes through the filter set, which for the current study was configured with three filters of 5 mm, 200 μm and 50 μm. Finally, in order to maintain the device with the most beneficial buoyancy and hydrodynamic conditions possible, the tail of the device has been designed with the fins shown in the figure, so that the water, already filtered, returns to the sea without causing turbulences that could destabilize it.

The operation of the MuMi sampler is based on a similar and parallel towed system as the trawl net, albeit simpler due to its smaller dimensions and with the difference that, in order to have real-time flow information, it is connected to a 12v socket to power the flowmeter. Once the transect mile has elapsed, the MuMi device was recovered by pulling the line. Then, the filters were removed for storage and subsequent analysis at the laboratory dependencies on land. Before starting the next transect, a new set of filters can be fitted.

2.3. Laboratory analysis

All samples were treated according to the same procedure, regardless of whether the samples were taken with the Manta net or with the MuMi device. The retained material was digested in three times the amount of 10 % potassium hydroxide (KOH) solution to remove organic material, as Thiele et al. (2019) recommend in their study and following Foekema et al. (2013) protocol. KOH is one of the most common oxidising solutions used for the treatment of organic matter. As such, it may not be exempt from generating possible polymeric changes in the particles under study, although it is not discouraged according to different authors (Lv et al., 2021; Sönmez et al., 2022). On the contrary, employed at the appropriate concentration and temperature (10 % KOH, at 40 °C), it is considered the least destructive treatment for the set of polymers most frequently found in microplastic samples (Karami et al., 2017). Samples in this study were digested at room temperature for 2–3 weeks, following the original protocol guideline of Foekema et al. (2013) as a conservative measure to prevent possible loss of particles in this step. Once the material was degraded, the remaining solution was filtered under vacuum through Whatman® glass microfiber filters (Grade GF/F, 47 mm), dried overnight at 60 °C and inspected under a stereomicroscope (Leica S9i). Following Montoto-Martínez et al. (2021b), number, size, colour and shape (fibres, fragments or pellets) of microplastic particles identified were recorded. The particles were measured and classified according to the following ranges: <1 mm, 1–2 mm, 3–4 mm and >5 mm. Although the smallest mesh size used (in the MuMi Sampler) was 50 μm, following the recommendations of Galgani et al. (2013) no particle was discarded even if it was below this threshold. Photographs of all potential microplastics were also taken.

2.4. Contamination controls

Fibre exclusion has been recommended for cases where airborne contamination may become difficult to control, as is the case for particularly large samples or samples handled in open or difficult to manage spaces (such as the digestive tracts of marine mammals or a necropsy room) (Lusher and Hernandez-Milian, 2018). In the present study, to address potential airborne contamination, and following AMAP recommendations, controls were performed both on the ship and in the laboratory by placing a wet filter over a petri dish in the operating areas during sample handling (Arctic Monitoring and Assessment Programme (AMAP), 2021).

Additional measures to limit the risk of sample contamination were implemented throughout: (1) Cotton lab clothes were worn during the analysis; (2) All equipment was cleaned and rinsed with Milli-Q water and checked under a stereomicroscope for airborne contamination before use; (3) Procedural blanks (250 mL of Milli-Q water run through the vacuum filtration system) were carried out, undergoing the same treatment as samples (exposure to air, digestion, vacuum filtration, etc.); (4) All samples were covered after each step of the procedure.

2.5. Statistical analysis

For statistical analysis, the concentrations of microplastics obtained from each sampling method were converted to number of particles per cubic meter. Although the MuMi sampler has an additional mesh of 50 μm, the comparisons made between methods refer to the particles found in the 200 μm mesh for both systems, unless otherwise specified. The data did not conform to parametric assumptions of normality and homogeneity of variance, therefore non-parametric tests (Wilcoxon rank sum tests) were used to compare the Manta versus MuMi methods. Similarly, Kruskal-Wallis rank sum tests were used to compare the concentrations of microplastics found with the different methods among the six transects. Statistical significances were assumed at $\alpha = 0.05$. All statistical analyses were done using the scripting language in an RStudio environment (RStudio Team, 2022). The map was produced using the software QGIS (QGIS Development Team, 2021).

3. Results

The two sampling devices were used simultaneously during the six transects, constraining the main differentiating factors, apart from the characteristics of each device itself, to two: the volume of water sampled and the mesh size.

The total volume filtered by the MuMi sampler, known from its built-in flowmeter, was 2224.8 L, with an average of 370.8 ± 80.5 L/NM (min. = 289.9 L; max. = 512.2 L). In contrast, estimates of the filtered volume made for the Manta net, which were based on the opening of its mouth (0.15 m^2) and the trawled distance (1 nm), following the calculations of Karlsson et al. (2020) returned a total of 833,400 L, corresponding to 138,900 L/NM (Table 1).

Both devices filtered the seawater through a mesh size of 200 μm, although MuMi had an additional one of 50 μm. The distribution of particles can be seen in Fig. 3, where the MuMi microplastics are further segregated according to the mesh in which they were found so that the comparison with the data from the Manta net can be made. All samples collected contained microplastics, with the total number of particles being 408: 269 (65.9 %) were filtered with the Manta net and 139 (34.1 %) with the MuMi sampler. According to their morphology, 250 fragments (61.3 %), 155 fibres (38 %) and 3 pellets (0.7 %) were identified.

Laboratory and field procedural blanks were run in parallel with samples and were analysed in the same way as other samples for microplastics. No particles were found on any of the control filters in the laboratory. A total of 9 fibres (similar to those recovered later in the samples) were found on the field control filters placed next to the mouth of the Manta net and the container into which the samples were transferred during the rinsing operation. The field controls for the MuMi sampler did not collect any particles.

The mean number of microplastics collected by the two systems,

Table 1
Number of particles, volumes of water filtered and resulting concentrations of microplastics reported with the different sampling modes for each of the transects.

Transect	Manta net			MuMi sampler		
	Volume (L)	N° MP	N° MP/m^3	Volume (L)	N° MP	N° MP/m^3
I	138,900.0	98	0.7	512.2	11	21.5
II	138,900.0	50	0.4	371.9	6	16.1
III	138,900.0	27	0.2	398.2	34	85.4
IV	138,900.0	41	0.3	289.9	16	55.2
V	138,900.0	13	0.1	302.6	36	119.0
VI	138,900.0	40	0.3	350.0	36	102.9

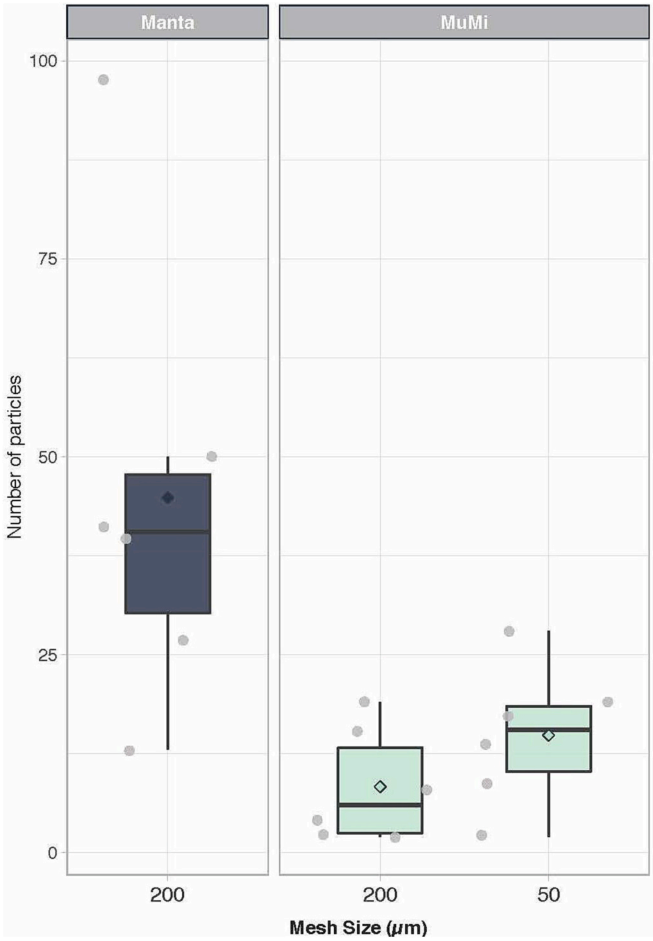

Fig. 3. Boxplot representing the microplastics collected in each of the transects (each of the grey dots) according to method and mesh size (where only MuMi has a 50 μm mesh size). The inner lines represent the median and the diamonds the mean.

considering exclusively the 200 μm mesh, was significantly different (Wilcoxon test, W = 34, p-value = 0.002165 < 0.05). The Manta net retrieved an average of 44.8 particles (min. = 13; max. = 98; sd = 29.1) against the 23.2 (min. = 6; max. = 36; sd = 13.7) that were collected by the MuMi, which correspond to 8.3 (min. = 2; max. = 19; sd = 7.2) and 14.8 (min. = 2; max. = 28; sd = 8.9) for the separate 200 and 50 μm meshes respectively. Fig. 3 shows the total particles collected by each method in each of the transects (grey dots), with a line representing the median and the inner diamond the mean.

In terms of colour distribution, in general there were mostly white, black, blue and colourless particles (Fig. 4). The predominance of clear particles (uncoloured and white) collected by the Manta net and blue particles collected by the MuMi sampler, which in turn correspond to a majority of fragments and fibres respectively, is noteworthy.

After converting the data to per volume of water sampled, the average concentrations are 0.3 MP/m^3 (min. = 0.1; max. = 0.7; sd = 0.2) for the Manta net and 66.6 MP/m^3 (sd = 42.7) for the MuMi sampler, corresponding to 23.3 MP/m^3 (min. = 3.9; max. = 54.3; sd = 19.9) and 43.3 MP/m^3 (min. = 5.4; max. = 92.5; sd = 30.3) if we consider the mesh sizes (200 and 50 μm) separately.

The differences in reported microplastic abundance (number of particles per cubic meter) are very notable (Wilcoxon test, *p*-value < 0.005), with the densities reported by the MuMi sampler being much higher than those of the Manta net for all transects (considering the 200 μm mesh exclusively). This can be seen in Fig. 5, where the abundance data have been transformed to the logarithmic scale so that the difference becomes evident.

The additional 50-micron mesh size of the MuMi collected 64 % of the total particles filtered by this device, a fraction that is differentiated in Fig. 6. In terms of particle morphology, the type of particle (fibre, fragment or pellet) predominantly collected by each of the sampling systems is notably different. The majority of the microplastics collected by the Manta net are fragments, compared to the 5 % that were collected by the MuMi sampler. Therefore, comparisons between methods or between transects are also necessarily linked to this factor, which is addressed in Section 4.4.1 of the discussion.

The differences in reported densities between the two methods are significant according to the *t*-test for paired samples (*p*-value = 0.01276 < 0.05). However, neither method shows a significant difference between transects. Therefore, in this work we consider the six transects carried out as six test replicates of both sampling methods.

Analyzing the results based on the size distribution of the particles identified, we find a predominance of particles between 1 and 2 mm (41.4 %) and between 3 and 4 mm (24.5 %). Fig. 7 shows how the larger the particle size, the fewer particles we found, both for the Manta net and the MuMi sampler. In the case of the latter system, we can see how the incorporation of the second mesh, with a smaller pore size, is responsible for capturing more than half of the total particles filtered by this system, specifically 89 microplastics, which correspond to 64 % of the total filtered.

4. Discussion

Our research shows that microplastic pollution is prevalent in the South of Tenerife. Particles were present in every sample regardless of the method used, with microplastic concentrations ranging from 0.1 to 92.5 particles/m^3 considering both methods. Sampling methodology influenced the estimated microplastic concentration, with the MuMi sampler reporting concentrations up to three orders of magnitude higher than the Manta net. Several studies have addressed the comparison of methods for microplastic sampling by varying mesh sizes, or sampling depths (Karlsson et al., 2020; Lusher et al., 2015, 2014; Zheng et al., 2021). In general terms, this study corroborates the issue addressed by Green et al. (2018) in the sense that data provided on the abundance of microplastics in the marine environment are highly variable depending on the sampling method used. This issue is also noted in the recent AMAP guidelines (2021), stressing caution when comparing results between studies that have been developed under different methodologies. This disparity has been further highlighted by Miller et al. (2021), who performed a comparison between neuston nets and a grabbing method in which the Manta net gave abundance results up to two orders of magnitude lower. Zhang et al. (2021) compared the results obtained after sampling the waters of the Lijiang River in China with sieves and plankton nets of different mesh sizes and found very significant differences between methods which they attribute, in part, to the different volumes filtered, which differed by up to three orders of magnitude, as in our results.

With the present study the aim was to keep as many variables in common as possible (mesh size, simultaneity in the distance travelled, same navigation speed and sampling depth, …), thus being able to evaluate the differences in the microplastic data being reported depending on the type of equipment used and the drawbacks it may present. The following subsections discuss some of the issues that have emerged from the comparison carried out. Special emphasis is placed on two key factors: the volume of water sampled, and the mesh size used. In addition, we also reflect on the conditions of operability of both methods, which serve to highlight the advantages and disadvantages of each method, and the windows of opportunity and improvement in each case. Finally, although the main objective of this study is rather methodological, the quantitative results also provide us with a baseline layer of information on microplastic pollution in this study area, which is very important because of the biodiversity it hosts and the anthropic pressure

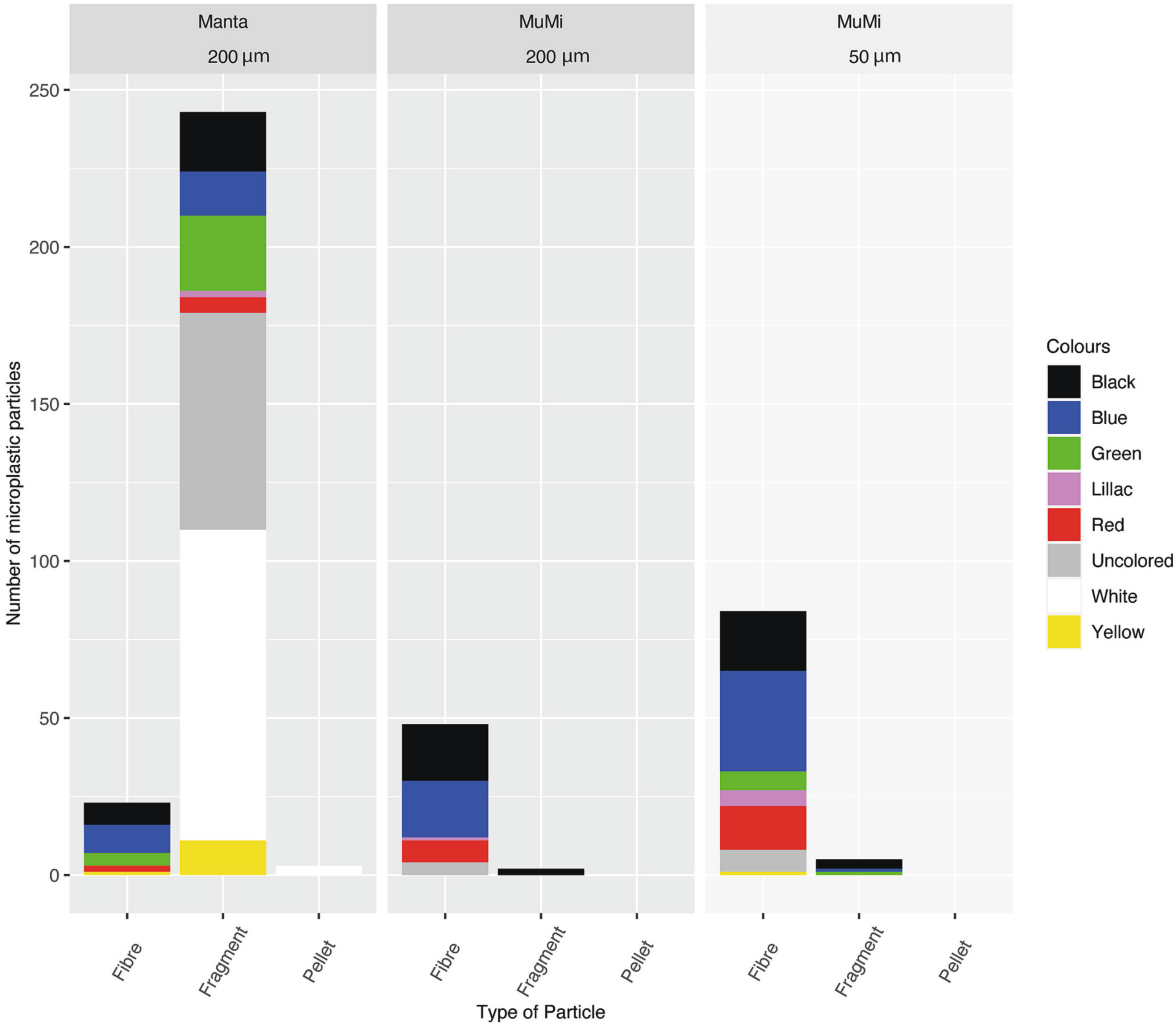

Fig. 4. Colour distribution of identified microplastics. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

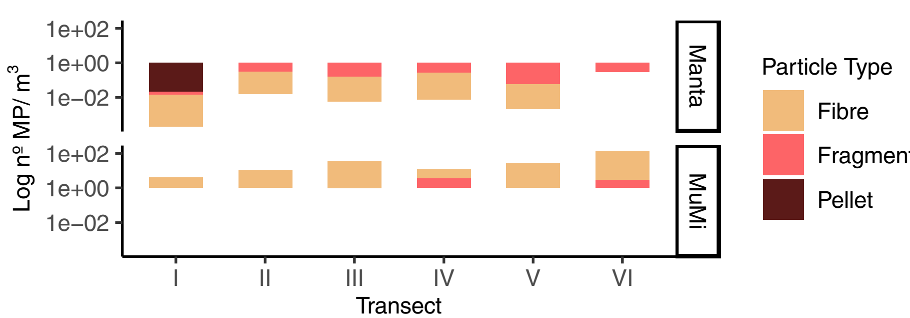

Fig. 5. Abundance of particles found at each transect according to sampling mode and differentiated according to morphology. Only the particles found in the 200 µm mesh are considered.

it is subjected to.

4.1. Operation comparison

The launch routine of the two sampling systems was quite similar. Once the vessel was located at the starting point of the transect, both devices, previously tied together with tow lines, were launched into the water from the stern of the vessel. Once the transect was completed, both devices were retrieved from the water by pulling on the anchor lines. In this sense, the operation with the MuMi, given its more manageable dimensions, was somewhat simpler. Although both can be carried out without the need for great technical requirements on the part

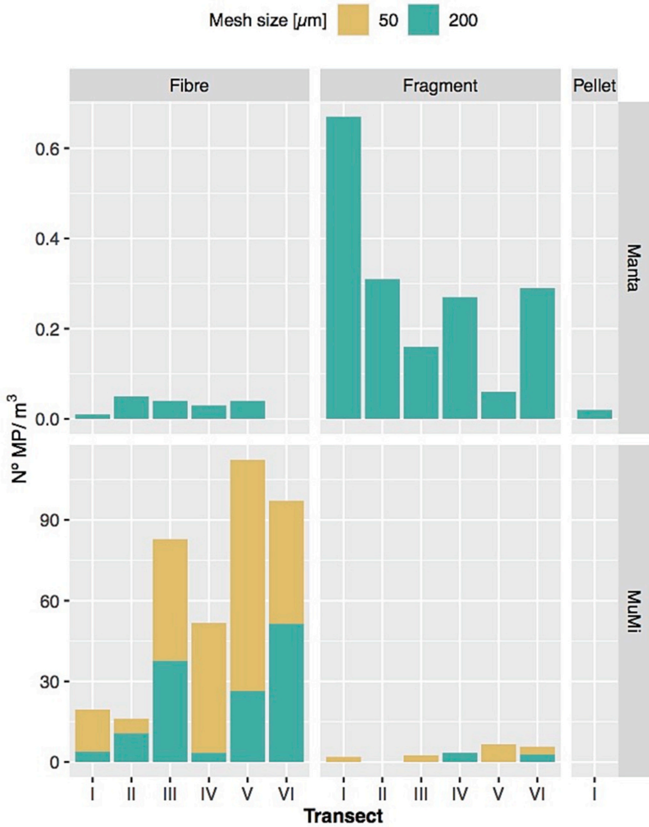

Fig. 6. Barplots representing the distribution of microplastics identified with each of the sampling systems, differentiated according to mesh size and particle type. Note different scale ranges for vertical axes, indicating the abundance of particles (n° microplastics/m^3).

of the boat, the launch and subsequent recovery of the Manta net requires at least two people.

Once the devices are on board, one of the principal differences is the time to obtain and store the samples in an appropriate manner to limit contamination and to prepare the instrument for a new cast. In this respect, the possibility of using interchangeable and new filters on each of the transects offered by the MuMi is very advantageous. The procedure with the Manta net requires the transfer of the particles retained in the net to the jars by washing the mesh, with the consequent risk of airborne contamination. Also, this procedure carries the risk of accumulating particles that have not been cleaned well from the net from one transect to another, or that the fabric is more clogged with organic matter in the final transects compared to the initial ones, and therefore filtering with a lower mesh size. On the other hand, the replacement of used filters with new ones with the MuMi sampler is a quick and clean process, thus minimizing the number of steps and the open exposure of the sample to avoid contamination risks, as its recommended in the AMAP Monitoring Guidelines (Arctic Monitoring and Assessment Programme (AMAP), 2021). In addition, the use of unique and interchangeable filters also allows for fast operation at sea, an issue that is also relevant especially when operating on board vessels of opportunity.

Furthermore, since the Manta net also collects larger quantities of organic matter and organisms associated with the sea surface, this also entails a longer sample processing time. In fact, it is recommended to avoid sampling using the trawl during the evening, as it will likely result in high volumes of zooplankton as they migrate to the surface at dusk (GESAMP, 2019). The digestion of this organic matter, using 10 % KOH at room temperature, can take up to several weeks to reduce to levels low enough not to hinder visual identification under the microscope (Lusher et al., 2017), so that even being more representative of the environment given the greater volume of water it filters, the Manta net has the disadvantage of being much more expensive in terms of the time invested to analyse the samples. As expressed in the work of Prata et al. (2020), in which volume experiments for microplastic sampling are performed, samples resulting from higher volumes are lower in quality due to the abundance of organic and mineral matter, which may conceal microplastics. However, for future studies, it would be interesting to optimize the organic matter alkaline digestion protocol according to the GESAMP recommendations, which suggest using 40 mL of 10 M KOH for every 0.2 g dry weight of sample maintained at 60 °C for 24 h (GESAMP, 2019). This latter method has proven to be very effective in removing biogenic material ingested by fish (Lusher et al., 2017; Rochman et al., 2015). Precisely according to AMAP's publication on this topic (2021), there is still much scope for increasing the quality and reducing the time and costs of these procedures in the current state of the art.

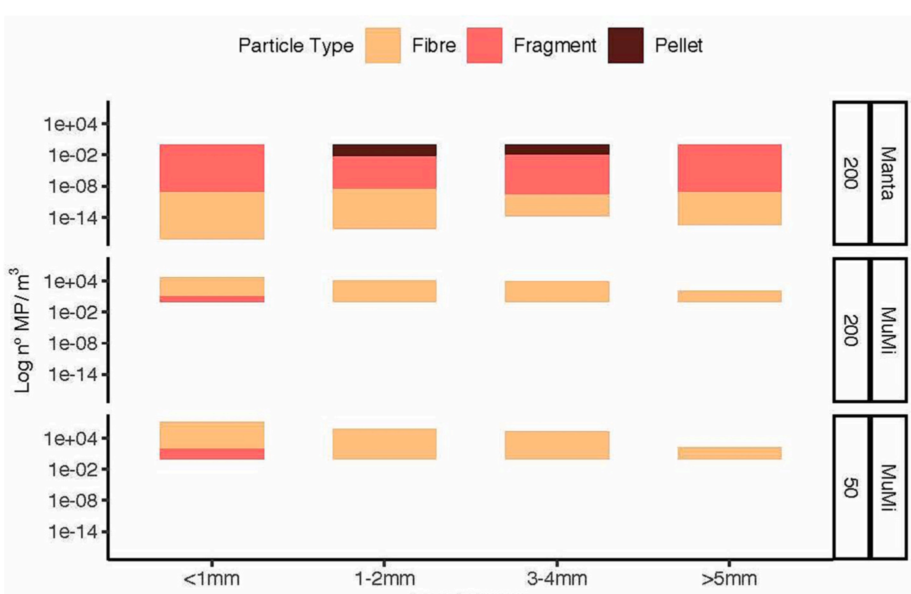

Fig. 7. Microplastic particle size distribution by sampling mode and particle type.

4.2. Sampling volume

One of the key differences in the comparison of the Manta net and the MuMi sampler is the amount of water sampled. This question brings with it three factors that, based on the results obtained, have proven to be fundamental for the analysis and comparison of microplastic reports. These three factors, which we delve into in the sections below, have to do with (1) the certainty of knowing the volume of filtered water, (2) the reproducibility of the volumes obtained, so that the results can be satisfactorily replicated, and (3) the representativeness of the particles obtained according to the filtered volume.

4.2.1. Volume filtered certainty

Knowing the exact volume of filtered water is one of the weak points of the sampling systems based on net trawling. After analyzing 35 studies published in 2021 on the monitoring or sampling of microplastics with Manta, we can conclude that the use of flowmeters has spread thoroughly, being an incorporated element in 66 % of the articles. However, it is also worth highlighting the fact that, even incorporating a flowmeter, its position in the net frame does not allow the precise volume of water filtered by the net to be measured, but an estimate must necessarily be made based on the size of the mouth of the structure, its degree of immersion and a theoretical factor, as explained in Liu et al. (2021) and Suteja et al. (2021). As expressed by Razeghi et al. (2021), as the net's immersion depth changes constantly with waves, wind and boat movement, it is difficult to estimate the exact volume of water being filtered. In fact, in some of these studies the Manta net is used with the built-in flow meter but the results are still reported per area covered (Bowman et al., 2021; Okuku et al., 2021).

In our case, the volume of water collected by the Manta net was calculated following the estimates made by Karlsson et al. (2020), which are based on the net opening and the distance travelled. The uncertainty in volume is probably the biggest unreliability in sampling with a trawl, being an area where there is room for innovative approaches to measuring it more accurately.

Precisely due to the fact that, even when incorporating a flowmeter, the estimates of the filtered volumes can be very disparate between replicates (Karlsson et al., 2020), the repeatability of the volumes reported when carrying out a monitoring study can also be a disadvantage of trawls as a sampling method compared to samplers such as the MuMi or others of similar performance.

As a result of this study, of the six transects carried out, the estimated volumes for the Manta net were 138.9 m^3, while the real values for the MuMi sampler were between 0.29 and 0.51 m^3 per transect, with an average of 0.37 m^3 (sd = 0.08 m^3).

If instead of measuring the volume filtered with the MuMi sampler with the flowmeter we had estimated it, we could have made an error of up to 8 % in reporting the microplastic concentration data, as the litres of variance are roughly equivalent to five misestimated particles. The variations in the volumes are due to the fact that the criterion for establishing the transects was taken as a nautical mile sailed, and not to reach a specific volume. Therefore, knowing the exact filtered volume is a clear advantage of the MuMi sampler over the Manta net that not only gives more accurate concentration data, but also provides precise and therefore reproducible sampling volumes.

4.2.2. Representativeness of volumes

Large sample volumes are often desirable because they are less affected by heterogeneity in the spatial scale of surface waters, an issue that particularly affects larger microparticles (Miller et al., 2021). In this regard, a characteristic asset in this case of the Manta net compared to the MuMi sampler is its ability to filter large volumes of water over a short period of time (Tamminga et al., 2019). However, given the intensity of the work and the time involved in collecting, processing and analyzing each sample, collecting the smallest possible sample size is a very worthwhile approach when designing an experiment. As Prata et al. (2020) state in their study, filtering the minimum volume necessary has the advantage of giving the possibility of taking more replicates in the area and therefore obtaining more representative data on the concentration of microplastics. It is known that the distribution of microplastics is not homogeneous either at the surface or in the water column (Sönmez et al., 2022), so in order to better understand the distribution of microplastics, as well as their transport, it is interesting to be able to use the sampling effort to carry out a larger sampling grid, covering a greater number of stations or transects, and therefore providing more detailed and concise information.

In this study there were not enough replicates to be able to establish and recommend a threshold detection volume, but specific studies have been carried out by other authors. According to research carried out by Lenz and Labrenz (2018) filtered water volumes can be reduced as the target particle size decreases without losing representativeness. That is, for the largest microplastics (above 200–300 μm), whose concentrations are usually less than one particle per cubic meter, it is therefore necessary to sample several times this volume. However, reported concentrations of smaller microplastics are up to two orders of magnitude higher, so that sampling volumes can be reduced without loss of sampling effectiveness. In our case, the mean number of particles per cubic meter obtained was 66.7 (sd = 42.7) for the MuMi case (covering the smallest sizes with the 50 μm mesh), compared to 0.3 (sd = 0.2) for the Manta net case. Therefore, the minimum volume requirements are different for each system. Other replicate reproducibility studies have also been carried out for small microplastics recommending volumes of 0.5–1 L for future studies (Prata et al., 2020). Ultimately, the volume of water required will be dependent on the presence of anthropogenic and organic items per sample (Arctic Monitoring and Assessment Programme (AMAP), 2021).

In order to see how far the volume could be reduced without losing representativeness, Karlsson et al. (2020) performed a comparative sampling between the Manta net and a pumped filtration method determining the minimum number of particles per sample that should be recorded in order to avoid false negatives. For the volume collected and based on the results of a statistical estimation, a minimum of 26 particles per sample is considered. This corresponds to a 20 % relative standard deviation calculated from a Poisson probability density function, which is less than the actual sample variability (55 %).

Performing the same statistical treatment for our case study, we can state that for both the Manta and MuMi samplers, a sufficient number of particles were filtered out for the samples to be representative. In the case of the Manta net, the estimated relative standard deviation is 14.94 % (compared to 64.96 % variability in the actual observations). For the MuMi case, the observed variability is 59.05 % while, with a mean of 23.2 particles, the relative standard deviation reaches a similar percentage (20.76 %) as for the 26 in the above-mentioned study Fig. 8 shows the probability density functions for both devices. Note that in the case of the MuMi the distribution is bimodal, which corresponds to the two meshes incorporated in this device (200 and 50 μm), as opposed to the single 200 μm mesh of the Manta net.

4.3. Mesh size

Mesh size largely influence concentrations reported (Prata et al., 2019). Sampling using Manta nets is usually configured with nets between 200 and 330 μm. In fact, maintaining these mesh sizes for monitoring environmental samples is desirable, so that the results can be compared with previous reports, as recommended in the Guidelines for Harmonizing Ocean Surface Microplastic Monitoring Methods (Michida et al., 2019).

In this study, a 200 μm mesh was used for both the Manta net and the MuMi sampler. Still, the abundance of particles reported by both methods excluding those particles retained on the additional 50 μm mesh was significantly different (Fig. 7). And including this fraction, the difference was several orders of magnitude more for the MuMi reports

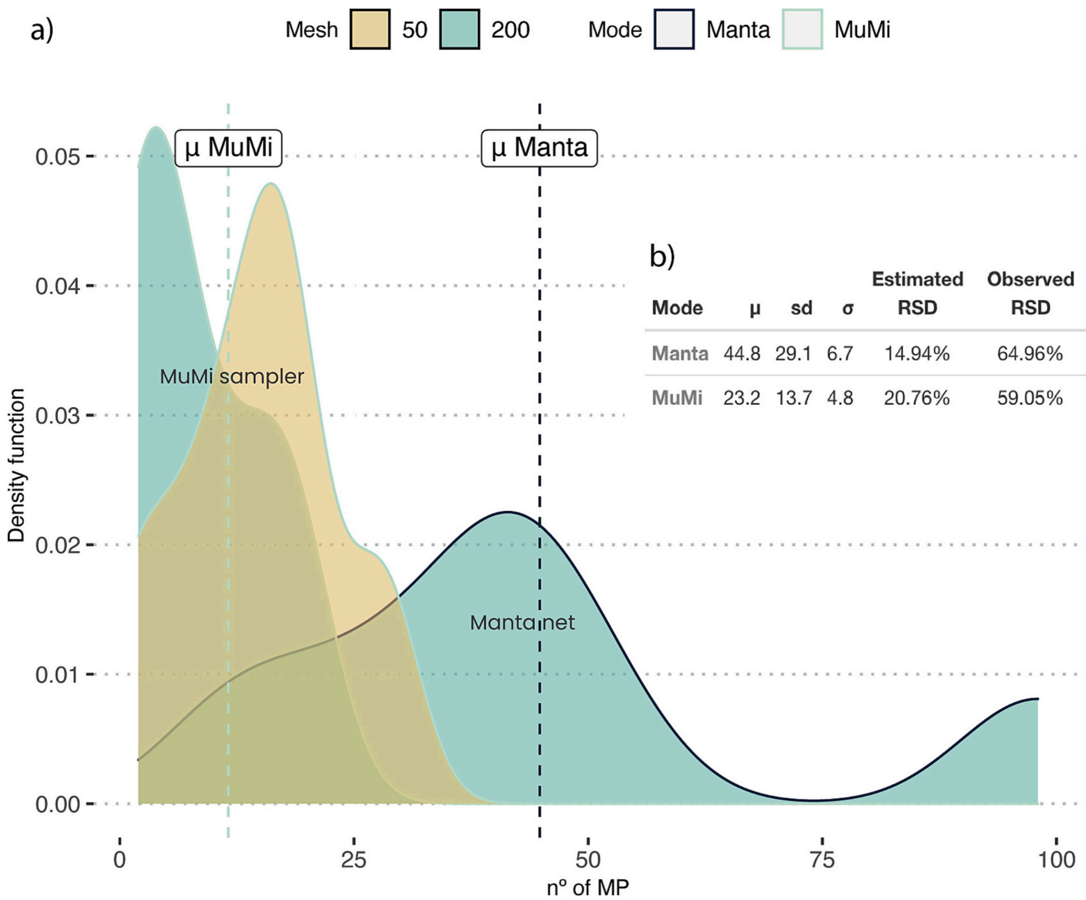

Fig. 8. a) Density plot of the number of microplastics according to sampling mode. The mean number of microplastics filtered with each method is indicated. b) Data used for the statistical estimation of the representativeness of the sample, where μ is the mean of the particles filtered by each method, sd the standard deviation of these observations and σ the variance calculated from the statistical estimation based on the study by Karlsson et al. (2020), from which the relative standard deviation is obtained (Estimated RSD) and compared with the observed one (Observed RSD).

than for the Manta net. In particular, having an additional finer mesh in the MuMi sampler contributed 64 % to the total count of particles identified by this sampling system, thus demonstrating the importance of obtaining data on smaller particles, not only because of their potential risk, but also because of their proven abundance in the environment (Rochman, 2015).

In this sense, Lindeque et al. (2020) already highlighted in their publication the underestimation that occurs in the collection of the smallest microplastics with traditional sampling methods. Furthermore, the reported concentrations could be increased up to 10-fold when using a 100 μm mesh instead of a 500 μm mesh, or 2.5 times using a 100 μm net compared to a 333 μm net. Also, Kang et al. (2015) identified 0.62–860 microplastics/m^3 using a 330 μm Manta trawl and 21–15,560 microplastics/m^3 using a 50 μm hand net in the Nakdong River mouth in the Southern Sea of Korea. In the same vein, Vermaire et al. (2017) found that a nylon net (100 μm) revealed concentrations almost a hundred times higher than a Manta net (333 μm), 100 and 1.35 particles per cubic meter, respectively. In like manner, Dris et al. (2018) also asserted that using an 80 μm versus a 330 μm sampling mesh increased the possibility of sampling fibres by 250 times.

Finally, concerning the meshes used, the fact of not filtering directly on the 50 μm mesh-filter, but having a roughing filter and a 200 μm filter arranged beforehand, contributed effectively to its good functioning, without any clogging occurring in any of the transects carried out. In this regard, the previous experience in the study by Enders et al. (2015) where an initial target of filtering with a 10 μm mesh had to be replaced by a 50 μm mesh due to clogging, was helpful in setting out the details of the methodology in the present study.

4.4. Differences in the characteristics of the collected particles

4.4.1. Predominance by particle type

The type of particles that each sampler preferentially collects presents differences. In the case of the Manta net, fragments and pellets account for 91.45 % (246/269) of the total particles, while fibres account for only 8.55 %. On the other hand, the opposite is true for the MuMi: with only 7 fragments collected, corresponding to 5 % of the total. The counting of fibres is not free from suspicion of airborne contamination, especially when studies are carried out in spaces that cannot be as controlled as a clean laboratory environment. In this regard, precautions should be taken both during sample handling on the ship and in the laboratory, carrying out the controls recommended by AMAP (2021) and carefully following the identification guidelines of Lusher and Hernandez-Milian (2018).

The differences in concentrations between the trawl and the MuMi in the current study could be conditioned by two determining factors that directly affect the type of particle filtered. These would be (1) the response of each device to the different hydrodynamic conditions to which they are subjected with respect to the fragments, and (2) the variation in sampling depth, which at first seemed to be negligible. This difference in particle preference trapped by each approach was also revealed in the comparative test by Green et al. (2018) who compared bottle grab and zooplankton net sampling methods, and by Song et al. (2014), who corroborated, after comparing different surface water sampling modes, that both the number and type of particles varied depending on the collection method used.

The most abundant form of marine debris in the surface ocean is millimetre-sized fragments with an average material density of 965 kg/m^3, that is less than the surface water density of 1027 kg/m^3 (Morét-Ferguson et al., 2010). In their study on the effect of wind mixing on the vertical distribution of buoyant plastic particles, Kukulka et al. (2012) state that, being passive particles, they are subjected to the physics of mixing processes at the ocean surface. Thus, the movements of microplastics in the water column are mainly driven by their density, size and shape but can also be modified by turbulence. Consequently, regarding the fragments, according to our point of view, the fact that the Manta net mainly filters this type of particles compared to the MuMi sampler may be related to the hydrodynamics of particles, which are larger and have a greater surface area in relation to their length. Despite the fact that the Manta net is mounted on a structure that also generates turbulence, these particles also have more margin to be intercepted in their trajectory by the net. Moreover, the degree of turbulence generated by the microplastic sampler on the surface in relation to the small diameter of its inlet mouth may be conditioning the entry of the fragments into the sampler.

As for the fibres, a hypothesis that can explain the disparity of results (where 95 % of the particles filtered by the MuMi were fibres, compared to 1.7 % filtered by the Manta net) may be related to a minimal but relevant difference in the sampling depth of both devices. This has been mentioned previously by other authors as a possible explanation (Michida et al., 2019), and is also linked to differences in the relative densities of the different particle types.

Although both devices were installed in such a way that they sampled the surface waters, the Manta net is placed so that half of its opening is always above the ocean surface, so that it always collects the particles that float in the most superficial layer of the ocean. However, the MuMi, having a much smaller opening, is configured so that its buoyancy is less, so that it can go submerged and filter water, and not bounce on the surface of the sea. This configuration, therefore, can affect the sampling of this surface microlayer, skipping it in parts of its path.

This limitation is common to sampling systems based on water pumping, as explained Zobkov et al. (2019) in their work: the dynamics of buoyancy and particle accumulation causes fibres to dominate the sub-surface layers while fragments, which have a higher buoyancy due to their weight-to-surface ratio, are more present in the surface layer. As also corroborated by other authors, this centimeter difference can be key in determining the type of particle collected by each method (Song et al., 2014).

4.4.2. *Sizes*

The fragmentation of larger marine litter and plastics into smaller pieces is well known (Hidalgo-Ruz et al., 2012) which justifies the fact that as the size class decreases, the abundance of particles increases (Tokai et al., 2021). Most of the particles identified were between 1 and 4 mm, which is consistent with the counts in the study by Eriksen et al. (2014) counting microplastics from 24 expeditions (2007–2013) across all five sub-tropical gyres, coastal Australia, Bay of Bengal and the Mediterranean Sea conducting surface net tows ($N = 680$), where 57.5 % of the particles were classified in the size range 1.01 to 4.75 mm.

It is also worth mentioning that although the particle samples were analysed separately according to the mesh size at which they were retained, the particle sizes assigned to each particle are given by the optical microscope measurements and are not linked to the mesh size. That is, a 3 mm long fibre may have been retained in the 50 μm mesh and therefore be counted in the 3–4 mm size, as we see in Fig. 7, where in the 50 μm mesh section we find observations for all size ranges. In this way, misinterpretation of particle sizes is avoided.

4.4.3. *Colour*

The analysis of the colour of microplastic particles is an issue that involves some uncontrolled variability in the data, such as being open to subjective sorting of different shades according to observers or different classifications designated in different studies. Therefore, the results, we believe, must be taken as a qualitative descriptive aspect, of which we can make some brief points. In addition, photo-oxidation processes induce changes in both the colour and the mechanical properties of the plastic polymers, so that even the colour of the particles may not be the original one. In this sense, we agree with the criteria of Hartmann et al. (2019), in which they emphasise that colour is not crucial in a categorization framework, despite its inclusion as an additional descriptor may make sense.

Martí et al. (2020) hypothesise a progressive discolouration of plastic marine litter, also an indicator of the age of the samples taken. Thus, of the total number of particles collected and identified in this study, almost half (47.79 %) had light colours or discoloured shades. This percentage rises to 71.6 % if we consider only the fragments, since up to 99 white fragments were counted among the particles collected by the Manta net. On the other hand, the predominant colour of the fibres was red, blue and black, which were also predominant (>80 %) in a previous study carried out with surface water samples also from the Atlantic Ocean (Montoto-Martínez et al., 2020).

4.5. *Comparative summary*

The AMAP guidelines (2021) dedicate a specific section to the importance of harmonization and standardization in the work with microplastics. The document reflects on both terms and the differences they entail: (1) Standardization requires the establishment of specific methods, limiting the flexibility of procedures between different research groups but allowing for more comparable results; (2) Harmonization, on the other hand, allows the use of different methods, always providing the necessary metadata and technical details and the techniques having been rigorously tested, so that the results obtained are also comparable. According to AMAP, standardized protocols are currently very limited in microplastics research and the scientific community is often testing new methods for harmonization while reporting data as a source of information to be compared with other studies.

Even within the same work team, not all monitoring opportunities count with the same means or resources, which is why we consider it essential to speak of harmonization in a flexible sense, without attempting to arrive at a single method, as also expressed Lusher et al. (2021). In this sense, one of the best practices is to openly share the experiences of the different monitoring programmes at national and international level (from sampling to sample treatment or processing) thus facilitating coordination and strengthening data sets so that it is possible to establish global patterns and trends. In addition to this, we believe that it is advisable to leave room for innovation and even combine different methodological perspectives that allow us to obtain the most complete picture possible of microplastic contamination, as proposed by Martin et al. (2022).

Thus, with the present study and starting from this point of view regarding the subject, the intention was to contribute to the harmonization and promotion of the monitoring of microplastics in surface marine waters. From our experiences in previous studies and the references consulted, we have gathered a number of features, pros and cons of each of the sampling methods compared: the Manta net and the MuMi sampler (Table 2). As other authors have previously suggested (Barrows, 2017; Mai et al., 2018; Tamminga et al., 2019), we consider a combination of methods to be the best option for future research, as it allows to obtain a most complete and contrasted information. However, as this will not always be possible, we should be aware of the limitations of the one we use. Likewise, as previously introduced, generating data that are comparable with other areas or with previous studies in the same area is a must in environmental pollutant monitoring. Critical aspects such as mesh size, sampled volume or depth of operation should be specially taken into account. Yet at the same time, issues more related to logistics and the time and resources available to the scientific teams are also relevant. Thus, the cost and maintenance of the device, or the sample processing time are two key advantages of MuMi. Moreover, the

Table 2
Comparison of the main features of the two sampling systems: Manta net and MuMi sampler.

Features	Manta net	MuMi sampler
Launching	The launch needs to be coordinated between at least two people so that the structure does not tip over.	Given its small size, launching is simpler.
Operation with rough sea conditions	Not possible.	Not possible.
Volume certainty	Incorporation of flowmeter possible but still not very accurate.	Yes, real-time flow information.
Volume reproducibility	No. Large differences in volumes reported with equivalent sampling characteristics in other studies.	Yes, the real-time reading of the flow meter and the short time to retrieve the device allows for this.
Volume representativeness	Most likely, if it was accurate.	More critical, but seems enough for smaller microplastics.
Sample handling time between replicates	Long: water jets to clean the net between transects.	Short: interchangeable and new filters on each of the transects.
Sample processing time at the laboratory	Long: captures more organic matter that can take several weeks to digest.	Short: the small size of the filter makes it relatively quick to observe.
Possibility to operate with varying and smaller mesh sizes	Meshes smaller than 200 µm are easily clogged.	It allows the placement of several filters, reaching smaller mesh sizes (50 µm).
Use of interchangeable and new filters on each of the transects	No	Yes
Risk of contamination	Higher. It can accumulate particles from one replicate to another by not rinsing well.	Minor. The device is compact and closed.

possibility of manufacturing the device by 3D printing at low cost and its simple operation make this device a very suitable candidate for monitoring sampling by vessels of opportunity, such as recreational vessels, or even those for artisanal fishing or whale watching tourism.

Microplastic contamination is strongly characterized by an often irregular dispersion over the sea surface and influenced by numerous physical, chemical, biological and climatic factors that can lead to large variations in counts even in contiguous or simultaneous replicates over time. Given these facts, the use of MuMi also has advantages in this regard as it allows representative samples to be obtained with a smaller sampling volume. In turn, it allows a greater number of replicates to be covered without disproportionately increasing the sampling effort and subsequent processing time of the samples.

5. Conclusions

This study compares two methods for sampling microplastics in marine waters: the Manta net and the MuMi sampler, an innovative microplastic sampling device protected as utility model.

Although it was demonstrated that the volume of water filtered with each device was adequate, the particle concentrations reported were uneven, with the average concentrations being 0.3 (sd = 0.2) for the Manta net and 66.6 (sd = 42.7) for the MuMi sampler. These variations are mainly attributed to the design of the sampler and the sampling strategy itself, such as the lack of control over the sample depth in continuous sampling.

Certainly, control over the filtered volume is an issue to be improved in trawl sampling methods. The MuMi sampler shows important advantages in different aspects: ease of operation, lower cost, smaller microplastics target size and greater precision, all while maintaining the representativeness of the collected samples. Among the aspects to be improved is the control over the sampling depth, which will also allow to further investigate differences in vertical distribution.

CRediT authorship contribution statement

Tania Montoto-Martínez: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Carmen Meléndez-Díez:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Abisai Melián-Ramírez:** Methodology, Software, Resources, Data curation, Visualization. **José Joaquín Hernández-Brito:** Conceptualization, Resources, Supervision, Project administration, Funding acquisition. **Mª. Dolores Gelado-Caballero:** Conceptualization, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Montoto-Martinez, Tania has patent #Dispositivo de muestreo de microplásticos (ES 1 270 147 U) licensed to Utility Model.

Data availability

Data will be made available on request.

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