Original Paper

Microplastics on the coasts of San Cristobal, Galapagos: a threat to the archipelago

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Abstract. *This study aimed to evaluate the presence and characteristics of microplastics on Mann, Lobos, Puta Carola, and Puerto Chino beaches. Water and sand samples were collected and analyzed for microplastic particles, considering factors such as size, color, and type. Each sampling point was meticulously georeferenced to track distribution patterns. Microplastics were* *extracted using a flotation process and identified using a stereomicroscope. The analysis confirmed the presence of microplastics on Puerto Chino beach, with the highest concentrations observed in the sand. Particles smaller than 1mm and 2mm were the most abundant, and blue was the predominant color. These findings shed light on the microplastic contamination in the Galapagos Islands, underscoring the urgent need for further research and mitigation strategies. Raising public awareness and implementing responsible waste management practices are critical steps towards protecting the delicate Galapagos ecosystem from the detrimental effects of microplastic pollution.*

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1. Introduction

Physical and chemical anthropogenic influences on the Earth system have reached a level comparable to that of natural geophysical processes (Steffen et al., 2011; De Souza Machado et al., 2018). As a result, human activities are among the most important drivers of ecosystem functions and threats to biodiversity (De Souza Machado et al., 2018).

Mass production of plastics began in the 1940s with the manufacture of a large number of different types (Mitrano and Wohlleben, 2020). As a result, there is growing concern about the increase in microplastics (plastic particles <5 mm) that contaminate different environmental compartments (Giráldez Álvarez et al., 2020; Rillig and Lehmann, 2020; Casso-Gaspar et al., 2022). These have increased in recent decades, with production increasing almost 200 times, reaching 320 million tons worldwide (Castañeta et al., 2020). Scientific research has shown the negative impact of plastic pollution on the oceans, as its mismanagement affects marine biodiversity (Rivera-Garibay et al., 2020).

Plastic pollution has become a global crisis, with millions of tons accumulating annually in both terrestrial and marine environments. Representing a staggering 20-30% of municipal solid waste by volume, plastic poses severe threats to ecosystems worldwide (Sumathi et al., 2016). While recycling and incineration efforts account for only 10% and 24% of plastic production respectively, the remaining 66% remains unmanaged, exacerbating the problem (Sumathi et al., 2016).

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Although plastic constitutes a relatively small portion (10%) of municipal waste by mass, it accounts for a shocking 85% of marine debris, primarily originating from land-based sources (Rhodes, 2018). While ocean pollution has garnered significant attention, freshwater ecosystems are increasingly impacted by plastic contamination (Lebreton et al., 2017).

On land, the accumulation of macro and microplastics in soils and natural areas is disrupting vital ecosystem functions. These plastic particles alter soil properties, hindering plant growth and potentially impacting broader ecological processes (Rillig & Lehmann, 2020).

Ecuador, a country with a significant coastal profile made up of five provinces along the so-called sun route, contains 64% of its waste from plastics, with the highest density found on the southern beaches of the Guayas province, which are mostly dragged by river currents (Gaibor et al., 2020). In 2020, the waters contained an approximate of 112 m^3 of microplastics, compared to the 41.28 m^3 registered in 2008, of which a massive increase of 160.90 m^3 is expected by 2030 (Pinargote, 2020).

Beach debris accumulation occurs worldwide, primarily composed of 60% to 80% plastic waste (Davis and Murphy, 2015; Gaibor et al., 2020b; Watts et al., 2017). Plastic waste can be transported to beaches through various pathways, including tides, wind, land transport, or even being directly discarded by beach visitors (De La Torre et al., 2020; Honorato Zimmer et al., 2019; Lavers and Bond, 2017; Serra Gonçalves et al., 2019).

The Galápagos Islands, a highly protected UNESCO World Heritage Site renowned for its endemic biodiversity, are not immune to the growing concern of the biological and socioeconomic impacts of plastic pollution (Jones et al., 2022). A study by (Villarreal, 2017) revealed the highest microplastic volume on San Cristobal Island, covering 128.7 mm3/m3. Floating plastics carried by the Humboldt Current (extending from southern Chile to the west coast of South America, reaching Ecuador and the Galápagos Islands) are considered a significant source entering the Galápagos Marine Reserve (Jones et al., 2021; Mestanza et al., 2019; Van Sebille et al., 2015), posing threats to the aquatic system as microplastics are ingested particulate matter (Figure 1.) (Rehse et al., 2016), playing a crucial role as a disease vector in the marine environment (Kirstein et al., 2016).

Current research on microplastics in the Galapagos Islands is notably deficient. There is a critical absence of longitudinal studies to establish long-term trends, understand the specific impacts on endemic species, and accurately identify local contamination sources. Additionally, the interaction between microplastics and chemical pollutants remains largely unexplored. Monitoring microplastic pollution on beaches across space and time is crucial to understanding its ecological impacts and guiding mitigation efforts. Therefore, this study aims to evaluate the presence of microplastics on Mann, Lobos, Punta Carola, and Puerto Chino beaches in San Cristobal canton, Galápagos province (Ecuador), to determine the current level of plastic pollution.

2. Methodology

2.1 Study area

Fieldwork was conducted between September 2023 and March 2024, with sample collection focused on the southern region of San Cristóbal Canton, Galápagos Province, covering four beaches: Mann (209571.483 - 9900901.013), Lobos (209165.696 - 9900136.129), Punta Carola (209261.390 - 9901519.185), and Puerto Chino (229583.746 9897546.624) (Figure 1). A two-month sampling period was deemed sufficient to gather representative data and establish a baseline for subsequent research and management initiatives. This timeframe allowed for efficient logistical planning, resource allocation, and the implementation of robust data collection and analysis methodologies. An exploratory descriptive study was conducted with a qualitative-quantitative approach as established by Torres (2016), since sand and water sampling were carried out on the mentioned beaches in order to identify the quantity, size, and color of microplastics present in the study areas.

2.2 Sand sampling

Sand sampling was conducted along the high tide line in a 100-meter transect, consisting of four sampling points of 0.5 meters by 0.5 meters with a distance of 25 meters, following the methodology outlined by Olaya (2020). Sand samples were collected using an aluminum spoon, to a depth of 10 cm from the surface between the high tide lines, where three samples were taken in each transect and deposited in a 1 L glass Kilner jar, avoiding any presence of water (González, 2019; Horton et al., 2017).

The samples were labeled with the following information: location, date, area, coordinates, and transect number. Samples were taken every five days after the first sampling for three weeks.

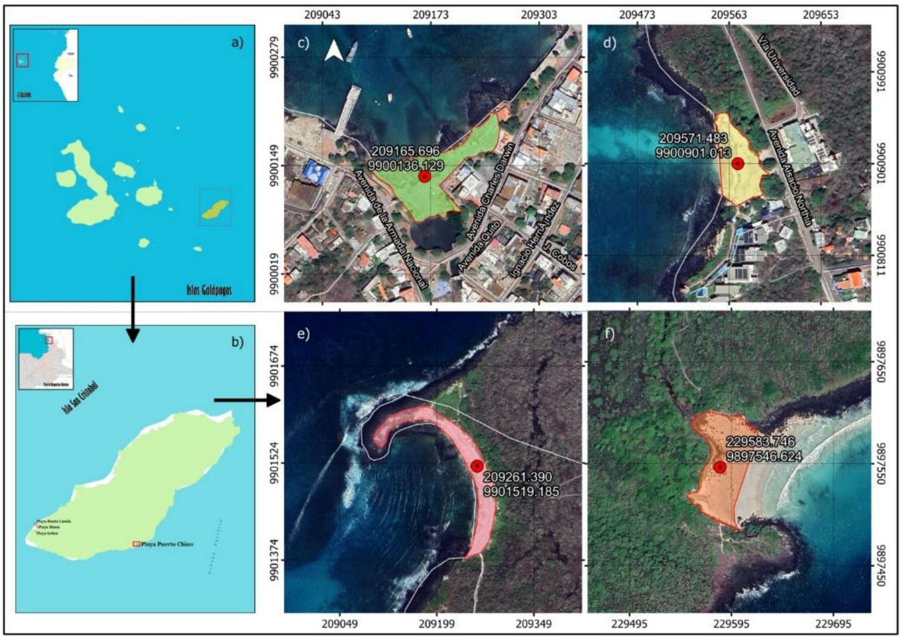

Figure 1. a) Galapagos province in Ecuador, b) San Cristobal Island, c) Lobos beach, d) Mann beach, e) Punta Carola beach, f) Puerto Chino beach.

2.3 Sampling of marine surface water

For water sampling, a 200 µm unweighted plankton net with a 200 µm mesh window and a flow meter was used, towing against the wind. GPS readings were taken at the beginning and end of each sampling point. However, due to the regulations established by the Galapagos Regulations for Maritime Tourist Transport Vessels, it was not possible to comply with the sampling protocol for microplastics on the sea surface as indicated by Gómez & Vélez (2023) and Kovač et al. (2016) at 3 of the 4 beaches. The plankton net was manually towed through the seawater surface for 2 to 10 minutes at a speed of 2 knots in duplicate.

2.4 Extraction of microplastics in sand and water samples

The density separation and flotation method proposed by Urban et al. (2020) was used to extract microplastics from sand and water samples. This method involved separating microplastics from water and sediment samples for quantification and characterization. The sieving method described by Crawford and Quinn (2017) was used as a reference for identifying microplastics in surface water. The samples were analyzed in the laboratories of the San Francisco de Quito University (USFQ) extension on San Cristobal Island.

2.5 Quantification of microplastics

Microplastics were identified using a stereomicroscope (Marine and Environmental Research Institute, 2019). Microplastics were classified by particle size (5mm, 4mm, 3mm, 2mm, 1mm), color, and type. The data obtained were used to estimate the total amount of microplastics on the beaches studied.

3. Results and discussion

The results of this study revealed the presence of microplastic particles (<5mm) on all four beaches sampled. Additionally, the presence of particles (<1mm) was observed in both sand and water (Figure 2).

Figure 2. Plastic particles (> 5mm) in sand.

Table 1 (see Appendix 1) details the results corresponding to the color, type, size, and quantities of plastic particle units (<5 mm) and (<1 mm) identified in the sand of the four beaches in San Cristobal canton.

Puerto Chino beach presented microplastics with a quantity of 37.375 units/kg, of which 0.1% corresponds to the fiber type and 99.9% to the solid type. Specifically, the distribution shows that 10 predominant microplastic color groups were identified with 31.6% blue, 22.2% green, 13.3% red, 8.7% light blue, 8.6% yellow, 7.1% orange, 3.9% pink, 2.7% purple, 1.7% black and 0.1% blue fiber (Figure 3). Recent studies have reported that the ingestion of MP by wild fish could be related to the availability, size, shape and color of plastic particles (Dos Santos et al., 2020), with blue being the preferred color for fish ingestion.

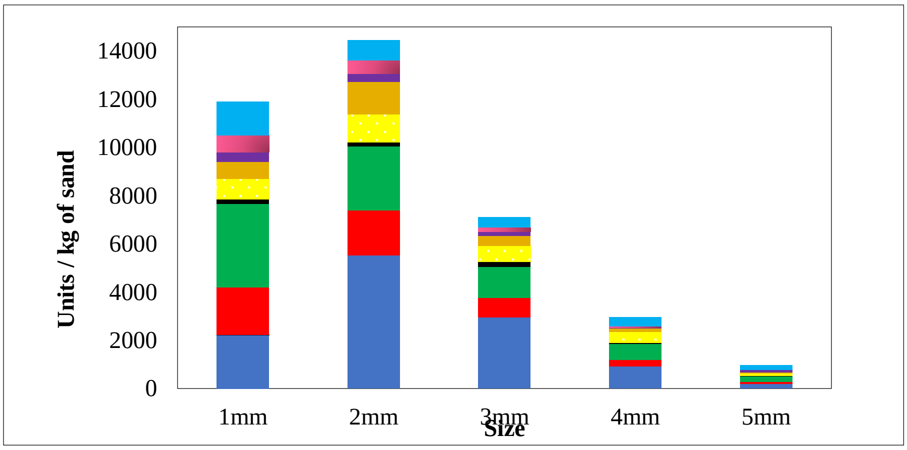

Figure 3. Microplastics identified by color and size obtained from the sand of Puerto Chino beach.

Figure 3 shows the fractions corresponding to each color of microplastics classified by particle size of <5 mm - 1 mm obtained from the sand of Puerto Chino beach. There is a higher concentration of microplastics, especially in the 2 mm and 1 mm sizes, with values of 14,450 and 11,900 units/kg of sand. Consecutively, a quantity of 7,100 units/kg of microplastics with a size of 3 mm is shown, 2,950 units/k with diameters of 4 mm. Finally, a lower presence of microplastics of <5 mm registering 975 units/kg of sand. On the Tortuga Bay beach line, the mean microplastic concentration (1–5 mm) ± SD was 74 ± 43 particles m−2. This high concentration is similar to those recorded in the Azores Archipelago on the edge of the North Atlantic gyre (with an average of >500 particles·m−2 in the top 10 mm) (Pham et al., 2020)

In the microplastic analysis, it was determined that among the predominant colors associated with each particle size, green plastics of 1 mm (29%) and 5 mm (23%) and in the case of microplastics of 2 mm (38%), 3 mm (42%) and 4 mm (31%) blue color predominates.

Similarly, on Puerto Chino beach, a concentration of particles less than <1mm was identified equal to 500 units/kg, of which 8% corresponds to the nylon type plastic, 51% to the fiber type and 41% to the solid type. In addition, the specific distribution shows that 11 predominant color groups were identified with 38% blue fiber, 12% yellow, 12% blue, 10% red fiber, 8% red, 8% white nylon, 3% purple, 3% brown fiber, 2% green, 2% orange and 2% pink.

On Punta Carola beach, a concentration of particles (<1mm) was identified equal to 533 units/kg, of which 33% corresponds to the nylon type plastic, 44% to the fiber type and 23% to the solid type. The specific distribution shows that 8 predominant color groups were identified with 33% corresponding to white nylon, 30% to blue fiber, 14% to red fiber, 8% to green solid, 6% to blue solid, 5% to red solid, 3% to light blue solid and 2% to orange solid.

On Lobos beach, a concentration of plastic particles (1mm) was identified equal to 1,644 units/kg, of which 11.8% corresponds to the nylon type plastic, 26.6% to the fiber type and 61.6% to the solid type; identifying 10 predominant color groups with 20.9% blue fiber, 18.6% red, 14.1% purple, 12.5% blue, 11.8% white nylon, 9.1% light blue, 5.7% red fiber, 3% green, 1.9% orange, 1.9% yellow and 0.4% pink.

On Mann beach, a concentration of plastic particles (<1mm) was identified equal to 225 units/kg, of which 83.3% corresponds to the fiber type plastic and 16.7% to the solid type. In addition, the specific distribution shows that 5 predominant color groups were identified with 66.7% blue fiber, 16.7% red fiber, 5.6% purple, 5.6% light blue and 6.5% yellow.

Table 2 (see Appendix 2) details the results corresponding to the color and quantities of plastic particle units (<1mm) identified in seawater (20m from the high tide line) on the four beaches of San Cristobal canton.

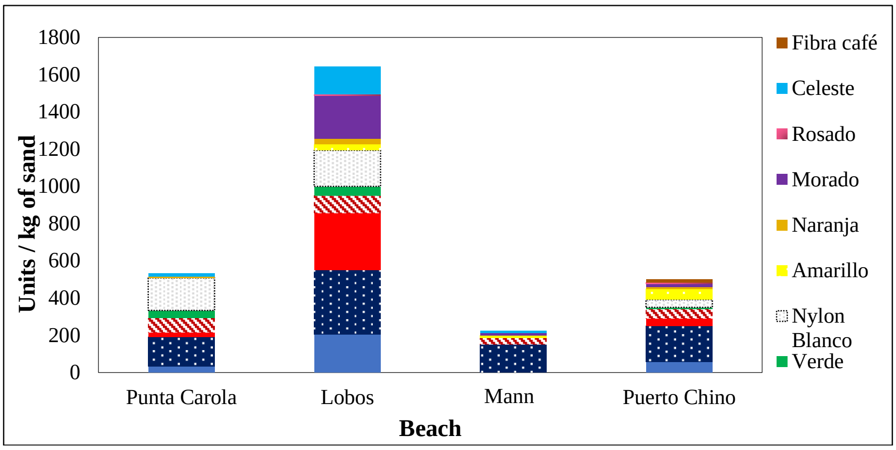

Figure 4. illustrates the fractions corresponding to each predominant particle color (>1mm) in the sand samples from the four beaches studied.

In the seawater of Puerto Chino beach, a concentration of <1mm particles was identified equal to 54 units per liter of water, of which 18% corresponds to the fiber type plastic and 82% to the solid type. In addition, the specific distribution shows that 10 shades were identified, red with 37%, yellow 25%, blue fiber 11%, orange 7%, pink 7%, blue 4%, brown fiber 4%, red fiber 3%, light blue 3% and green 1%.

In the seawater of Punta Carola beach, a concentration of particles (<1mm) was identified equal to 104 units per liter of water, of which 7% corresponds to the nylon type plastic, 63% to the fiber type and 30% to the solid type; 8 predominant hue groups were identified with 53% blue fiber, 12% blue, 10% red fiber, 10% purple, 8% red, 7% white nylon, 1% green and 1% yellow.

In the seawater of Lobos beach, a concentration of <1mm plastic particles was identified, equal to 38 units per liter of water, of which 49% corresponds to the fiber type plastic and 51% to the solid type. Likewise, 7 predominant color groups were identified with 49% blue fiber, 18% blue, 13% light blue, 10% red, 7% purple, 1% green and 1% pink.

In the seawater of Mann beach, a concentration of particles (<1mm) was identified equal to 13 units per liter of water, of which 25% corresponds to the nylon type plastic, 42% to the fiber type and 33% to the solid type. In addition, the specific distribution shows that 5 color groups were identified, with 25% green, 25% red fiber, 25% white nylon, 17% blue fiber and 8% orange in seawater.

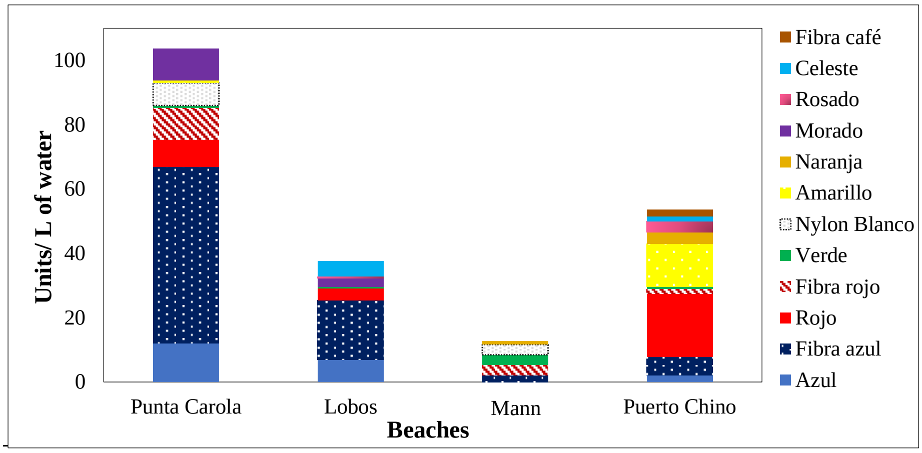

Figure 5. Plastic particle units <1mm identified by color in the seawater of San Cristobal beaches.

Plastics have become an environmental problem worldwide (Maxwell, 2021), due to the fact that tons of this polymer end up in the sea annually, causing pollution in the oceans and posing a danger to marine fauna due to its persistence and high toxicity (Barrera et al., 2023; Sánchez et al., 2022). Williamson et al. (2019) state that the environmental conditions of beaches cause the fragmentation and degradation of plastic waste into smaller sizes, eventually turning into microplastics (Lots et al., 2017).

Torrez et al. (2021) state that the ingestion of microplastics by marine species such as fish, birds, turtles, mammals and invertebrates is related to the size of microplastics available in the environment. Lusher (2015) states that in general, micrometers of plastics are easily ingested and expelled, however, nanometric plastics manage to pass through the cell membranes of species. Based on the above, there are various research works that report the presence of microplastics in the stomachs of mammals (Núñez, 2022), fish (Román et al., 2024), invertebrates (Astorga et al., 2022) and even the presence of microplastics in human placentas has been evidenced (Ragusa et al., 2021), which is why studies on plastics on beaches are sought to determine the level of contamination.

The analysis showed that the Puerto Chino beach showed the presence of microplastics in sand, with diameters of 2 mm (14450 units/kg) and 1mm (11900 units/kg). In addition, 5 color groups were identified, with blue being the predominant color for MP with diameters of 2 mm, 3 mm and 4 mm. In the research carried out by Torrez et al. (2021) on the beaches of Colima and Jalisco in Mexico, a total of 12001 microplastics were found in sand, and 12 colors were also identified, with blue being the most prevalent (45%). Olaya (2020) states that beaches are generally the areas that harbor a large amount of plastic waste.

In this study, it was determined that the largest amount of plastic particles (<1mm) in the San Cristobal canton was found on Lobos beach (1644 units/kg) in the sand samples, since the study area is an area destined for boating activities. These results differ from those achieved by Gómez & Vélez (2022) on the beach of San Jacinto, Manabi province, since microplastics were identified in various areas in this study site: fishing (1492 MP/m^2), tourist (490 MP/m^2) and area with less intervention (324 MP/m^2).

On the beaches of the coast of Peru, a microplastic study was carried out, reporting quantities of 19692 mg/cm3 on the Pozo de Lisas beach and 11358 mg/cm3 in Montecarlo (Dávila, 2021), values that are higher than those obtained on the Punta Carola beach with 104 units/L of particles (<1mm) in seawater on the island of San Cristobal, Galapagos. Acosta et al. (2022) state that microplastics are present in various environments, however, their presence is greater in saline waters in coastal areas.

In the research of Mindiola et al. (2016) carried out on three Galapagos islands (Santa Cruz, San Cristobal and Isabela), 669 MP particles were measured, determining that Santa Cruz Island exhibited the highest volume of microplastics (308706 mm3/L) and, San Cristobal Island reported a greater abundance of microplastics (34275 particles/L), the authors mention that the cause of this considerable amount of microplastics is due to marine currents according to the sampling season (October).

Regarding the coloration, it was identified that the most representative color on the beaches studied for sand corresponds to blue fiber that is generated by the breakage of cables or other activity. For its part, in the seawater samples, the predominant color was blue and blue fiber, in addition to colors such as green, red and yellow; classified as types of fiber, fragment and films that can come from plastic bags, disposable materials, among others. Mendoza and Mendoza (2020) mention that on the Mía beach in the city of Manta they found microplastics of similar colors (blue, yellow, green and red) to those identified on the beaches of San Cristobal, highlighting blue as the color with the highest percentage (40%). In addition, various types of microplastics were found: film (22%), fragment (30%) and fiber (48%).

In the investigations of Lino (2019), Torrez et al. (2021), Yagual (2023) and Ríos (2023) blue microplastics predominate significantly. Xiong et al. (2019) state that in the characterization of microplastics, the blue color will always prevail, given the abundance of blue MP that exist in the ocean. Mazariegos et al. (2021) state that this color has a high possibility of being absorbed by fish, since they can confuse their prey with microplastics. Van Sebille et al. (2021) argue that in the study carried out on the island of San Cristobal in the Galapagos, the most abundant types of microplastics are fragments (53%) and fibers (44%), while the results of Calle (2021) found fragments (49.10%) and fibers (40.75%) with white, green, orange and transparent colors. Villamar (2022) points out that in general the most frequent microplastics are: low density polyethylene (LDPE), high density polyethylene (HDPE), and polyethylene terephthalate (PET).

4. Conclusions

The findings support the modeled predictions that the Humboldt Current could be a major driver of the rate and spatial distribution of plastic accumulation in this part of the Galapagos Marine Reserve. Microplastics have a great impact on marine biota, especially on vertebrate fauna such as turtles, as well as on species included in the IUCN Red List. The prevalence of fiber-type microplastics gives us a clear idea of the failures in wastewater treatment plants (WWTPs) in countries, so research on microplastic sources is needed. The predominant particle size (<2 mm) and the predominant color is blue, associated with ease of consumption, as well as the resemblance to common prey. Appropriate conservation measures and management measures are needed to reduce the entry of microplastics into the Galapagos Sea ecosystem and protect its fragile and unique biodiversity.

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