

Microplastic distribution in the marine and freshwater ecosystems of Cocos Island National Park, Costa Rica

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Abstract. The presence of microplastics (MPs) has been documented in remote sites, including Cocos Island, an oceanic island in the Costa Rican Pacific Ocean, which serves as a temporary home to park rangers, researchers, volunteers, and tourists. While previous investigations have attributed the presence of MPs in the marine environment to ocean currents, doubts have arisen about the sources of MPs in the freshwater ecosystem. This study aimed to analyze the distribution of MPs in both the marine and freshwater ecosystems by collecting water, sediment, and biota samples from both environments. A total of 288 samples were assessed, resulting in the identification of 178 MPs. Statistical analyses revealed a uniform distribution of MPs around the island in both ecosystems, suggesting that the activities carried out by the island's inhabitants do not represent a significant source of MPs. The study also found higher abundance and larger-sized MPs in the marine ecosystem, which was expected. Drawing on findings from other studies in remote areas, sources of MPs in Cocos Island's freshwater ecosystem are likely linked to atmospheric deposition, air-sea exchange, long-range transport, and biovectors. Oceanic insular environments, such as Cocos Island, are particularly vulnerable to plastic pollution as they can retain plastics from adjacent seas through various oceanographic mechanisms. These results underscore the importance of considering microplastics as a planetary boundary threat. Understanding the distribution and sources of MPs in remote and ecologically sensitive areas is crucial for effective conservation and pollution management efforts.

1. Introduction

The plastics we encounter today consist of long chains of molecules called polymers, which mimic the natural polymers found in fibers such as silk or wool, giving them high flexibility. By the 1950s, plastics had become ubiquitous in American households, but as their production and use increased, so did their negative impacts. By the late 1950s, reports emerged of sea turtles



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ingesting plastic, and in the early 1960s, polymers were found in the digestive systems of seabirds. Furthermore, plastic debris became increasingly visible in the environment and on streets (CIEL, 2017).

Recent reviews have confirmed the pervasiveness of marine debris worldwide, affecting various marine habitats, organisms, and ecosystems (F.J. Kroon et al. 2018). Marine debris, including plastics, is categorized based on size (Barnes et al. 2009; GESAMP 2015; F. Kroon et al. 2018), from mega (>1 m diameter), macro (between 2.5 cm and <1 m), meso (between 5 mm and <2.5 cm), micro (between 0.1 μm and <5 mm) to nano (<0.1 μm). Plastics can undergo fragmentation and degradation in the environment due to factors such as photodegradation, weathering, water currents, and biodegradation mechanisms (Lestari, Trihadiningrum, Firdaus M, et al. 2021). Microplastics (MPs) have emerged as a significant concern in plastic degradation (F.J. Kroon et al. 2018).

Plastics have been detected in nearly every environmental compartment and ecosystem, including terrestrial, freshwater, marine ecosystems, the atmosphere, and biota (Bank and Hansson 2022). The MP contamination in marine ecosystems has been mainly attributed mainly to terrestrial runoff, plastic industrial waste, and human activities like fishing, aquaculture, tourism, and marine industries (Lusher et al. 2017). MPs in freshwater ecosystems present a complex scenario due to diverse environmental compartments and their role as recipients, sinks, and transporters of plastic pollution (Van Emmerik and Schwarz 2020).

Recent documentation of MPs in remote sites includes oceanic islands in the Atlantic Ocean (Monteiro et al. 2018), pristine mountain catchments in the French Pyrenees (Allen et al. 2019), coastal Antarctica, and the deep sea (Horton and Barnes 2020), among others. This has led to the emergence of new hypotheses about the sources, transport, and fate of MPs, such as atmospheric deposition (Horton and Barnes 2020; Padha et al. 2022), rainfall (Roblin et al. 2020), and breeding seabirds acting as MPs biovectors (Bourdages et al. 2021; Hamilton et al. 2021).

Cocos Island, situated in the Costa Rican Pacific Ocean, is an oceanic island with no permanent inhabitants but serves as a temporary home to park rangers, researchers, volunteers, and tourists. It is part of the Eastern Tropical Pacific Marine Corridor (CMAR), aimed at conserving biodiversity and marine and coastal resources in vital sites that gather significant marine biodiversity. CMAR connects the marine protected areas of Cocos Island (Costa Rica), Coiba Island (Panamá), Malpelo and Gorgona Islands (Colombia), the Galápagos Archipelago (Ecuador), and the Revillagigedo Archipelago (México) (CMAR 2019).

Due to growing concerns about MPs, LEMACO (Marine and Coastal Studies Laboratory) research group and FAICO (Cocos Island Friends Foundation) conducted an investigation to determine the presence of MPs in the marine and freshwater environments of Cocos Island National Park. Surprisingly, the study revealed the presence of MPs in both ecosystems. While the possible sources of contamination in the marine ecosystem were attributed to oceanic currents, doubts arose about the sources of MPs in the freshwater ecosystem, given the island's remoteness, being 532 km away from the nearest coast, and limited human activity (Astorga et al. 2022). To address these uncertainties, the present study represents the second phase of the aforementioned research, aiming to analyze the distribution of MPs in both marine and freshwater ecosystems by sampling water, sediments, and biota around the island.

2. Materials and Methods

2.1 Site

The study site, as illustrated in Figure 1, comprises several quadrants with designated sampling points. Quadrant B, situated in the Northeast, includes the two bays where officials' stations are located, namely Bahia Wafer and Bahia Chatam. Bahia Wafer serves as the central station where most of the officials' activities take place, while Bahia Chatam station is visited periodically, without daily presence of officials. The field expedition for sample collection was conducted from January 16th to February 14th, 2022, with the relevant permission R-001 PI-DR-ACMC-2022.

Samples were gathered from various environmental compartments in each quadrant, including marine and river water, marine and river sediments, marine lobsters, freshwater shrimps, marine fish, and freshwater fish. The sampling points within each quadrant were chosen randomly to ensure unbiased representation. However, access to the terrestrial environment on the island posed challenges, and only one river per quadrant was accessible for sampling purposes.

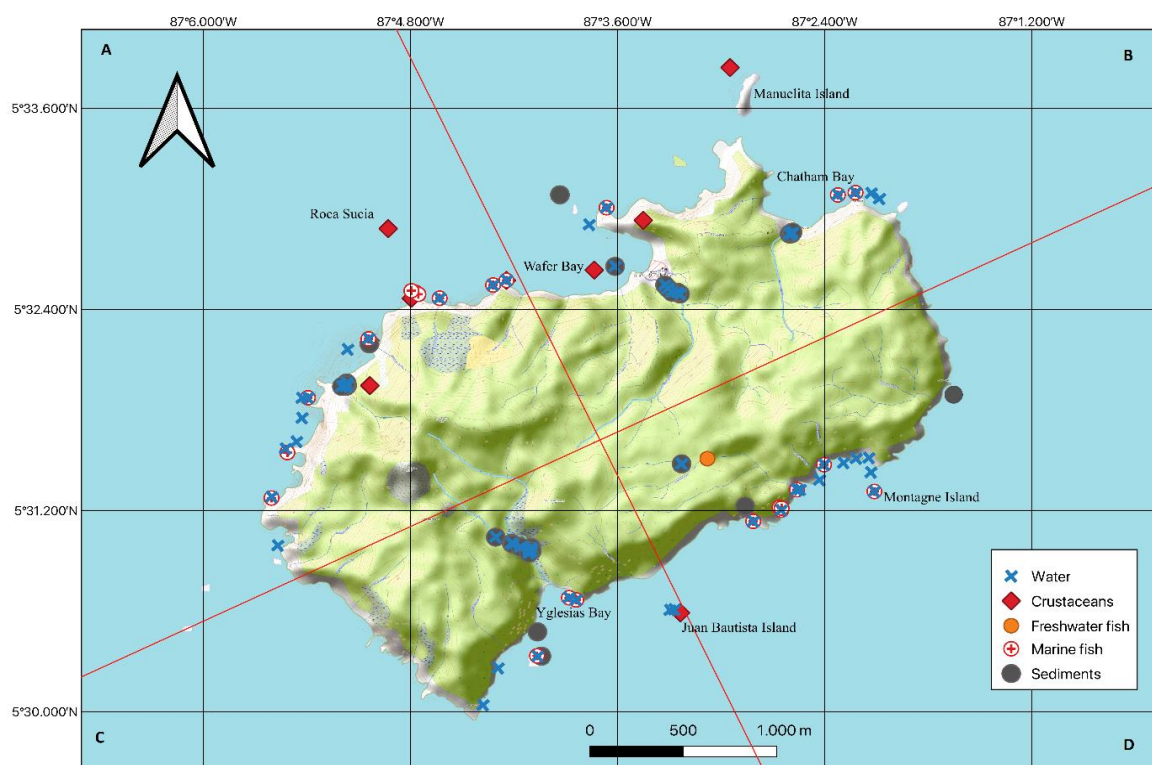


Figure 1. Collection sites and sample types from Cocos Island.

2.2 Sample collection

The sample collection process for the study involved obtaining four types of samples (water, sediments, fish, and crustaceans) from each ecosystem to investigate potential relationships between organisms and their feeding environments, as well as to compare the microplastics (MPs) found in each type of sample. An effort was made to equally sample the marine and terrestrial ecosystems, obtaining 288 samples. Table 1 summarizes the samples obtained by ecosystem, compartment, and quadrants.

Table 1. Quantity of samples taken according to the ecosystem, compartment, and quadrat on Cocos Island

Ecosystem	Sample type	Quadrant			
		A_Northwest	B_Northeast	C_Southeast	D_Southwest
Marine	Seawater	9	9	9	9
	Sediments	9	9	9	9
	Fish	9	9	9	9
	Lobsters	15	3	9	9
Freshwater (rivers)	Water	9	9	9	9
	Sediments	9	9	9	9
	Fish	9	11	9	9
	Shrimps	9	9	7	9

Marine and freshwater water: Water samples were collected manually from the surface using pre-washed one-liter aluminum bottles. The water was filtered through a 60 μm stainless steel sieve to remove solids, and the retained particles were transferred to glass bottles for laboratory analysis (Razeghi et al., 2021). Nine one-liter samples were collected from each quadrat, resulting in 36 marine and 36 freshwater water samples.

Marine and freshwater sediments: Marine sediment samples were collected at an average depth of 15 meters, while freshwater sediment samples were collected from the surface. Each sample weighed one kilogram and was obtained using clean stainless steel hand tools and stored in metal containers washed with distilled water. The metal containers were kept in freezers at 0°C until further processing (Herrera et al., 2018). Nine one-kilogram samples were collected from each quadrat, totalling 36 marine and 36 freshwater sediment samples.

Marine organisms: Marine fish were captured using fishing rods, and lobsters were collected by hand during scuba diving or snorkeling. The specimens were stored in aluminium buckets in a cooler for transport to the processing site. The collected marine species included *Lutjanus jordanii* (fish) and *Panulirus penicillatus* and *Panulirus gracilis* (lobsters). From each quadrat, nine marine fish were captured, resulting in 36 fish in total. Thirty-six lobsters were collected, although their distribution among quadrants varied due to the availability of the species at the respective sites.

Freshwater organisms: Freshwater organisms were randomly caught using small and fishing nets in the accessible rivers. The species collected included *Sicydium cocoensis* (fish) and *Macrobrachium* sp. (shrimp). Similar to the marine organisms, the freshwater fish and shrimp were stored in aluminium buckets within a cooler for transportation. From each quadrat, a total of 38 freshwater fish were collected, with 9 from quadrats A, C, and D, and 11 from quadrat B. For freshwater shrimps, a total of 34 organisms were collected.

Below, is a brief description of the sampling procedure, for further details, please refer to our previous work published in Marine and Fishery Sciences (2022) [<https://doi.org/10.47193/mafis.3532022010907>].

2.3 Sample processing

The sampling procedure is the same as the previous

The laboratory workspace was regularly cleaned to minimize contamination from external sources, such as airborne fibers. Processing mainly took place inside a laminar airflow cabinet, particularly during solution preparation, sieving, and filtration. Glassware was washed thoroughly, oven-dried, and covered with aluminum foil when not in use.

Water : The retained solids from water samples were transferred to glass Petri dishes, which were covered with aluminum foil to allow water evaporation while preventing airborne plastic contamination (Enders et al., 2020).

Sediments: Sediment samples underwent density separation using a sodium chloride (NaCl) solution (1.2 g cm⁻³) (Hidalgo-Ruz et al., 2012; Qiu et al., 2016). After stirring for 2 minutes, the sample was allowed to settle for 24 hours, and the supernatant was filtered through a 60 µm stainless steel sieve. The retained solids were transferred to glass Petri dishes and left to dry under similar conditions to water samples

Biota : Organisms were weighed and measured before dissection (Table 2). Lobsters and fish were dissected to remove the entire gastrointestinal tract (GIT), which was then preserved in glass containers with 70% ethanol (EtOH) (Boerger et al., 2010; Lusher et al., 2013). Freshwater shrimps were not dissected due to their small size; instead, the exoskeleton was removed, and the whole animal was preserved in ethanol. For laboratory processing, the GITs of lobsters and fish, along with freshwater shrimps, were chemically digested using a 10% potassium hydroxide (KOH) solution, as described by Cole et al. (2014) and Kühn et al. (2017). The samples were agitated in Erlenmeyer flasks in an incubator at 60°C for 24 hours before sieving through a 60 µm stainless steel sieve and evaporating the excess water at 45°C.

Table 2. Average measurements of the organisms collected on Cocos Island

Organism	Average weight (g)	Average total body length (cm)
Marine fish <i>Lutjanus Jordani</i>	563.8 ± 112.7	34.5 ± 2.7
Freshwater fish <i>Sicydium cocoensis</i>	7.0 ± 4.2	7.8 ± 1.7
Marine lobsters <i>Panulirus penicillatus</i> and <i>Panulirus gracilis</i>	528.7 ± 226.7	25.4 ± 2.8
Freshwater shrimps <i>Macrobrachium</i> sp	7.2 ± 5.8	6.8 ± 1.7

2.4 Observation, identification and validation of microplastics

Microplastic particles were counted and photographed using a stereo microscope (OPTIKA SZ-ST2) with an image analysis system (AMSCOPE MU1000 Camera and AMPSCOPE software). Particles were identified and classified by shape, color, and size according to previously established methods (Peng et al., 2017; Lestari et al., 2021). Four shapes of microplastics were observed: fibers, fragments, pellets, and films (Hidalgo-Ruz et al., 2012; Qiu et al., 2016). Microplastics were categorized into six colors: blue, black, yellow, translucent, white, and red. Particles longer than 5 mm were classified as mesoplastics and excluded from the results.

2.5 Quality control of experiments

Sample exposure to the environment was minimized during collection, processing, and analysis to reduce contamination. All tools and surfaces were cleaned with 70% EtOH and Milli-Q water before and between uses. During laboratory processing, samples were handled within a laminar flow cabinet to prevent airborne contamination by MPs (Zhang et al., 2017). Controls were carried

out throughout the process, with visual inspection ensuring that particles showing similarities to potential contaminants were not included in the final analysis (Kroon et al., 2018).

2.6 Statistical analysis

The abundance of MPs across sample types and ecosystems was tested for normality using the Shapiro-Wilk test. As the data were not normally distributed, non-parametric tests were applied: Mann-Whitney tests for comparisons between two independent samples, and Kruskal-Wallis tests for multiple comparisons between ecosystems and sample types. All statistical analyses were performed using R Statistical Software (R Core Team, 2020).

3. Results

3.1 Abundance and distribution of microplastics

MPs were abundantly present in both the marine and freshwater ecosystems, with a total of 178 MPs recorded. Among these, 113 (65%) MPs were found in the marine ecosystem, while 61 (35%) were detected in the freshwater ecosystem. A Mann-Whitney Test for Two Independent Samples revealed significant differences between the number of MPs in the marine and freshwater ecosystems (p -value = 0.0005), as well as the area (mm²) of plastic found (p -value = 0.008), with the marine ecosystem showing higher quantities. The frequency of occurrence of MPs was 42% in the marine ecosystem and 29% in the freshwater ecosystem.

To assess the distribution of MPs within the ecosystems, a Kruskal-Wallis test was performed for the quadrats. Surprisingly, no significant differences were observed in the number of MPs per sample and the area of plastic per sample between the quadrats in either ecosystem (p -value, marine ecosystem - quantity of MPs = 0.16; p -value, marine ecosystem - mm² of plastic/sample = 0.99; p -value, freshwater ecosystem - quantity of MPs = 0.3; freshwater ecosystem - mm² of plastic/sample = 0.96).

Table 3. Summary of the statistical analysis performed

Analysis	Test	Result
Number of MPs/sample between the marine and freshwater ecosystem	Mann-Whitney Test for Two Independent Samples	P value = 0.005*
Number of MPs/sample between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.45
Number of MPs/marine samples between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.16
Number of MPs/freshwater samples between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.99
Number of MPs/L between seawater and freshwater	Mann-Whitney Test for Two Independent Samples	P value = 0.0098*
Number of MPs/kg between marine and freshwater sediments	Mann-Whitney Test for Two Independent Samples	P value = 0.097
Number of MPs/organisms between marine and freshwater ecosystem	Mann-Whitney Test for Two Independent Samples	P value = 0.097
Number of MPs/organism between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.58
Number of MPs/marine fish versus the number of MPs/freshwater fish	Mann-Whitney Test for Two Independent Samples	P value = 0.45
Number of MPs/marine fish between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.56

Analysis	Test	Result
Number of MPs/freshwater fish between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.49
Number of MPs/marine lobster versus the number of MPs/freshwater shrimp	Mann-Whitney Test for Two Independent Samples	P value = 0.067
Number of MPs/marine lobster between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.42
Number of MPs/freshwater shrimp between quadrats (A, B, C, D)	Kruskal-Wallis Test	P value = 0.44
Number of MPs/sample between seawater, marine sediments, marine fish, and marine lobsters	Kruskal-Wallis Test	P value = 0.12
Number of MPs/sample between freshwater, freshwater sediments, freshwater fish, and freshwater shrimps	Kruskal-Wallis Test	P value = 0.81
Size (mm) of MPs between marine and freshwater	Mann-Whitney Test for Two Independent Samples	P value = 0.015* There is a significant difference, marine MPs are longer.
MP area (mm ²) between marine and freshwater MPs	Mann-Whitney Test for Two Independent Samples	P value = 0.34
Size (mm) of MPs between marine fish, freshwater fish, marine lobster, freshwater shrimp, marine sediments, freshwater sediments, seawater, freshwater	Kruskal-Wallis Test	P value = 0.0022* The null hypothesis is false, there is a significant difference between: Marine lobster and freshwater fish (p -value = 0.025*) Marine sediments and freshwater fish (p -value = 0.0077*) Marine sediments and freshwater (p -value = 0.036*)
Size (mm) of MPs between marine water and freshwater	Mann-Whitney Test for Two Independent Samples	P value = 0.078
Size (mm) of MPs between marine and freshwater sediments	Mann-Whitney Test for Two Independent Samples	P value = 0.094
Size (mm) of MPs between marine and freshwater fish	Mann-Whitney Test for Two Independent Samples	P value = 0.027
Size (mm) of MPs between marine lobsters and freshwater shrimps	Mann-Whitney Test for Two Independent Samples	P value = 0.27

* The null hypothesis is false, there is a significant difference.

Water samples: A total of 35 microplastic particles (MPs) were detected in the marine water samples, with an average amount of 1.94 ± 1.35 MPs/L in 47% of the positive samples. In contrast, the freshwater samples contained 15 MPs, with an average amount of 1.67 ± 1.00 MPs/L in 22% of the positive samples. The Mann-Whitney Test for Two Independent Samples showed a significant difference in the abundance of MPs between the two ecosystems (p -value = 0.009), with marine water having a higher amount per liter).

Sediment samples : In the marine sediments, a total of 27 MPs were identified, with an average of 1.4 ± 0.6 MPs per kilogram of sediment (MPs/kg) in 42% of the positive samples. Similarly, the freshwater sediments contained 12 MPs, with an average of 1.1 ± 1.3 MPs/kg in 31% of the positive samples. However, the Mann-Whitney Test did not find a significant difference in MPs/kg between the two ecosystems (p -value = 0.097).

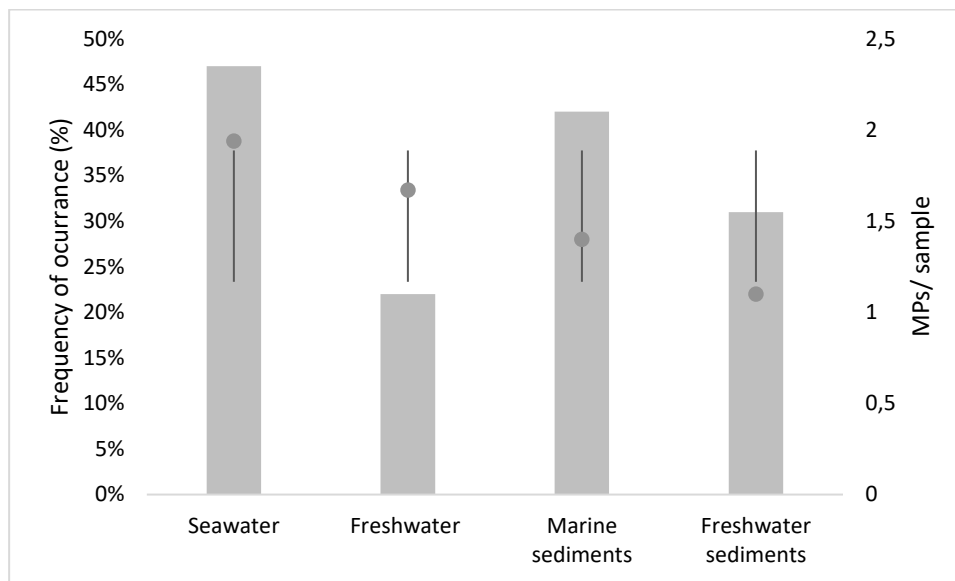


Figure 2. Results obtained in water and sediment samples on Cocos Island. Blue points mean the arithmetic mean, and bars mean standard deviations.

Biota samples : Among the marine fish, 15 MPs were found, with an average of 1.36 ± 0.67 MPs per fish and 31% of the positive samples. In comparison, freshwater fish contained 14 MPs, with an average of 1.24 ± 1.19 MPs per fish in 29% of the positive samples. The Mann-Whitney Test did not indicate a significant difference in MPs/fish between the two ecosystems (p -value = 0.44).

Regarding crustaceans, 42 MPs were identified in marine lobsters, with an average of 2.33 ± 1.61 MPs per lobster and 50% of the positive samples. In freshwater shrimps, 20 MPs were found, with an average of 1.82 ± 0.75 MPs per shrimp in 33% of the positive samples. The Mann-Whitney Test also did not show a significant difference in MPs/crustacean between the two ecosystems (p -value = 0.066).

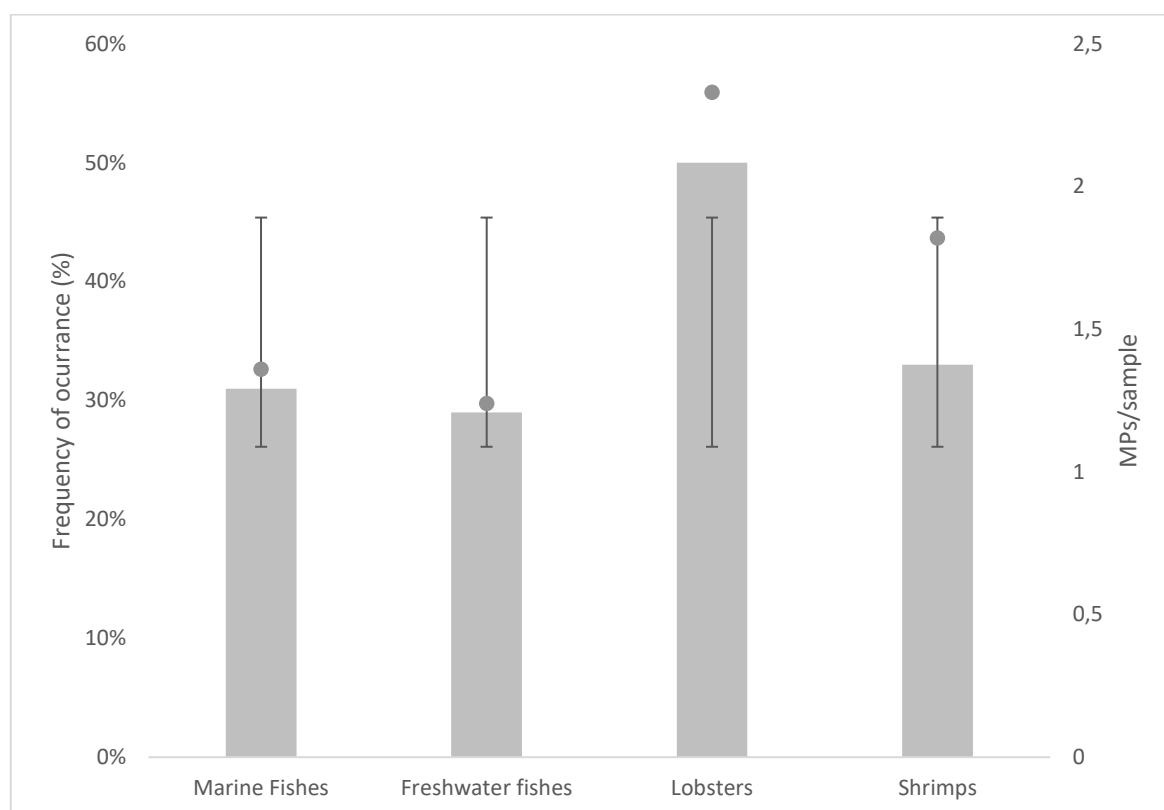


Figure 3. Results obtained in fishes and crustacean samples on Cocos Island. Blue points mean the arithmetic mean, and bars mean standard deviations.

3.2 Shape, color and size of microplastics

Out of the 174 microplastic (MP) particles found, fibers were the most prevalent shape in both marine and freshwater ecosystems, accounting for 88% and 70% of the MPs, respectively. Fragments were present in a small amount (8%) in each ecosystem, while films constituted 4% in the marine and 20% in the freshwater ecosystem. Pellets were only determined in the freshwater ecosystem, comprising 2% of the MPs (Fig. 3A). In terms of color, blue particles were the most abundant, accounting for 55% in the marine ecosystem and 54% in the freshwater ecosystem. Red and translucent particles followed, contributing 17-18% and 11-18%, respectively (Fig. 3B and Table 3).

Furthermore, the majority of microplastics in the marine ecosystem were large microplastics (LMP), comprising 55% of the total, while in the freshwater ecosystem, small microplastics (SMP) made up the majority at 56%. Mesoplastics were not shown in the results as they only constituted a small proportion of the total plastic particles in the study.

A Mann-Whitney Test for Two Independent Samples was performed to compare particle sizes between the marine and freshwater ecosystems, revealing a significant difference (p-value = 0.015). The average size of microplastics in the marine ecosystem was 1.52 ± 1.17 mm, whereas in the freshwater ecosystem, it was 1.11 ± 0.88 mm, indicating that the MP particles in the marine ecosystem are larger than those in the freshwater ecosystem. Additionally, comparisons were made using the Mann-Whitney Test for Two Independent Samples to analyze MP sizes among different sample types and between ecosystems. A significant difference (p-value = 0.028) was

observed between the sizes of microplastics in marine fish (0.8 mm) and freshwater fish (0.49 mm).

Table 4. Microplastic abundance in the marine and freshwater ecosystem of Coco Island categorized by (A) size, (B) shape, and (C) color.

Characteristic		Marine ecosystem	Freshwater ecosystem
MPs	Number of pieces	113	61
Size	Average mm	1.52 ± 1.17	1.11 ± 0.88
	SM	45%	56%
	LM	55%	44%
Shape	Fibers	88%	70%
	Fragments	8%	8%
	Film	4%	20%
	Pellet	0%	2%
Color	Blue	55%	54%
	Red	17%	18%
	Black	12%	5%
	Translucent	11%	18%
	Yellow	4%	3%
	White	1%	2%

4. Discussion

Out The PNIC, located in the American Pacific, is influenced by both superficial and submarine currents, with the North Equatorial Countercurrent reaching it as the first land point. The island experiences consistent rain, wind, and cloud cover throughout the year, with abundant freshwater flows in rivers and streams (SINAC 2016). Human activity on the island is generally low, primarily concentrated in Wafer Bay, where administration facilities, official's accommodations, surveillance centers, and other essential infrastructure are located. Tourism is limited to specific trails, while most of the island remains under minimal intervention, allowing only research, control, and protection activities (SINAC 2016). As a result, the anthropogenic impact on the island's freshwater ecosystem is relatively low.

Specifically, Quadrat B encompasses areas with active human activities, while the rest of the quadrats represent uninhabited or minimally intervened areas. Analyzing the distribution of microplastics across quadrats, we found no significant difference in the amount of microplastics per sample between Quadrat B and the other quadrats. This suggests that the distribution of microplastics is uniform around the island, indicating that the activities carried out by employees in the inhabited areas are not significant sources of microplastics for the island's freshwater ecosystem.

The remoteness of many islands, including the PNIC, is no longer a guarantee of protection against ocean-based sources of plastic marine debris. Despite its isolation, the marine ecosystem of the island is significantly affected by microplastics, primarily due to ocean currents (Monteiro et al. 2018). It is expected that the marine ecosystem would have a higher abundance and larger size of microplastics, given the influence of these currents. In contrast, the presence of microplastics in the freshwater ecosystem is of great concern, as human presence and activities are limited, eliminating the most common potential sources of microplastics (e.g., wastewater treatment plants, urban and industrial runoff) (Wagner et al. 2014). Consequently, the sources of microplastics in the freshwater ecosystem remain unknown, leading to a hypothesis that they may be linked to atmospheric deposition, air-sea exchange, long-range transport, and biovectors (Bank et al., 2022).

Research by (Bank and Hansson 2022) has shed light on the role of atmospheric deposition in dispersing microplastics on a global scale. Various studies have shown that microplastics from atmospheric deposition can be found in remote areas, including the French Pyrenees, the Alps, the Arctic, and ocean surface air (Dris et al. 2016; Peeken et al. 2018; Allen et al. 2019; Roblin et al. 2020). Surprisingly, remote sampling sites like the French Pyrenees exhibited levels of atmospheric microplastic deposition comparable to megacities like Dongguan and Paris (Dris et al. 2016; Liqi et al. 2017). Furthermore, wet atmospheric deposition has been identified as a significant pathway for microplastic transport, as demonstrated in remote sites in Ireland, where up to 70% of investigated microfibers were deposited through this mechanism (Roblin et al. 2020). Dry deposition of plastic also plays a crucial role in the global plastic cycle, especially for long-range and global transport, as revealed by (Brahney et al. 2020). While seabirds have been considered possible sources of microplastics in remote areas, such as the PNIC (Bourdages et al. 2021; Hamilton et al. 2021), their significance as a source of MPs remains unclear and requires further investigation.

The organisms sampled from each ecosystem were analyzed based on their feeding strategies and living habitats. The marine fish (*Lutjanus jordanii*) is associated with the seabed and exhibits carnivorous behavior, preying on benthic mobile crustaceans such as shrimp and crabs, as well as other organisms such as octopus, squid, cuttlefish, and bony fish (Allen 1985). On the other hand, the freshwater fish (*Sycidium cocoencis*) are demersal and primarily herbivorous (Hoese 1995). The marine lobsters (*Panulirus penicillatus* and *Panulirus gracilis*) are benthic and carnivorous (DecaNet eds 2023), while the freshwater prawns (*Macrobrachium* sp) are also demersal and carnivorous (García-Guerrero et al. 2013). The presence of microplastics (MPs) was confirmed in the four types of samples (water, sediment, fish, and crustaceans) from both ecosystems. However, no significant difference was found in the abundance of MPs per sample based on the organisms' feeding strategy and living habitat.

All the organisms analyzed in this sampling exhibit an affinity with the bottoms, either from rivers or from the sea. This shared characteristic could explain why no significant differences were observed in MP abundance based on feeding strategy and living habitat. To gain further insights, it may be valuable to compare these data with organisms that solely use and feed in the water column. However, such organisms were not present in the rivers of the Cocos Island, both among fish and crustaceans.

Additionally, the marine fish samples were compared with existing literature on gastrointestinal content analysis of filter feeders of the herring *Opisthonema* complex (Clupeiformes: Clupeidae) from the Central Pacific of Costa Rica (Bermúdez-Guzmán et al. 2020). In the literature, MPs were detected in 100% of the individuals, with an average of 36.7 pieces per fish, primarily comprising 79.5% fibers and 20.5% particles. In contrast, our marine fish samples showed that only 31% of them had MPs, with an average of 1.36 ± 0.67 MPs per fish, a significantly lower number of MPs compared to Bermúdez-Guzmán et al.'s study. One possible explanation for this difference may be related to the buoyancy of the plastic particles, affecting their distribution and availability to different organisms in the marine environment.

The physical characteristics of MPs were carefully assessed. Notably, a significant difference in the size of MPs was found between the two ecosystems, with marine MPs being longer than their freshwater counterparts. This size difference may have implications for the potential long-range transport of MPs through atmospheric deposition (Bank and Hansson 2022). Understanding the differences in MP size between marine and freshwater environments can help to better comprehend their dispersal patterns and environmental impact.

In addition to size, the shape and color of MPs were consistent in both ecosystems, with fibers being the most common type of MP and blue, red, and translucent hues dominating the color spectrum. The high occurrence of fibers aligns with their prevalence in marine systems worldwide (Desforges et al. 2014; Courtene-Jones et al. 2017; Bermúdez-Guzmán et al. 2020). The consistency in these physical characteristics across ecosystems may offer valuable insights into the sources and pathways of MPs in both marine and freshwater environments.

Oceanic insular environments, such as Cocos Island, are particularly vulnerable to plastic pollution due to their capacity to retain plastics from adjacent seas through various oceanographic mechanisms (Ivar do Sul et al. 2014; Worm et al. 2017). The results of this study underscore the need to view MPs as a significant planetary boundary threat. Effective governance strategies must be implemented urgently to address this pressing environmental issue. A Global Plastic Waste Partnership is essential to collaboratively determine and implement the most effective path forward in combating plastic pollution and protecting delicate island ecosystems like Cocos Island.

5. Conclusions

- The distribution of MP in the marine and freshwater ecosystem is uniform around the island; therefore, human activity by park rangers is not a significant source of MP.
- There is a higher abundance of MP in the marine ecosystem, and these are longer particles compared to the freshwater ecosystem.
- It should be evaluated whether indirect sources such as atmospheric deposition, air-sea exchange, long-range transport, and biovectors threaten the island's freshwater ecosystem.

6. Acknowledgments

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