ORIGINAL RESEARCH

Microplastics found in the World Heritage Site Cocos Island National Park, Costa Rica

Angélica Astorga[1], Andrea Montero-Cordero[2], Geiner Golfin-Duarte[3], Andrea García-Rojas[1], Hannia Vega-Bolaños[1], Fausto Arias-Zumbado[1], Daniela Solís-Adolio[1] and Karol Ulate[1,*]

[1]Universidad Nacional, Avenida 1, Calle 9 Heredia 86, 40101 - Heredia, Costa Rica. [2]Fundación Amigos de la Isla del Coco (FAICO), Barrio Escalante, de la Rotonda La Bandera 300 metros oeste Oficentro Casa Holanda oficina 11, 2603-1000 - San José, Costa Rica. [3]Sistema Nacional de Áreas de Conservación (SINAC), Costa Rica; angelica.astorga.perez@gmail.com (AA), amonterocordero@gmail.com (AMC), geiner.golfin@sinac.go.cr (GGD), andrea.garcia.rojas@una.ac.cr (AGR), hannia.vega.bolanos@una.ac.cr (HVB), fausto.arias.zumbado@una.cr (FAZ), dsolis.adolio@gmail.com (DSA). ORCID *Angélica Astorga* https://orcid.org/0000-0003-2373-0455, *Andrea Montero-Cordero* https://orcid.org/0000-0003-3537-3045, *Andrea García-Rojas* https://orcid.org/0000-0003-3451-7094, *Hannia Vega-Bolaños* https://orcid.org/0000-0002-9855-9747, *Fausto Arias-Zumbado* https://orcid.org/0000-0003-0391-592X, *Daniela Solís-Adolio* https://orcid.org/0000-0002-5063-1527, *Karol Ulate* https://orcid.org/0000-0001-5687-555X

ABSTRACT. Microplastics (MPs) defined as 'small' pieces of plastic < 5 mm have been found in almost every marine habitat around the world, and studies have shown that we can find them in the ocean surface, the water column, the seafloor, the shoreline, in biota and in the atmosphere-ocean interface. This study aimed to assess both marine and freshwater environments of Cocos Island, Costa Rica, in the Pacific Ocean, by sampling sediments and biota to determine the presence and abundance of this pollutant. Sediment samples were superficial and weighed one kilogram each. For the sampling of freshwater fish and shrimps, nonselective capture with small nets was made in rivers with access by land, while fishing rods were used for the marine fish sampling, and cage and scuba diving for lobsters. Plastics were found in all types of samples: 93% of marine sediments, 32% of freshwater sediments, 20% of freshwater fish, 15% of freshwater shrimps, 27% of marine fish, and 51% of marine lobsters. Like many reports around the world, it was expected to find MPs at marine samples, and it was concluded that ocean currents, tourism activities, and discarded fishing gear from illegal fishing activities could be the sources of marine pollutants. In contrast, the amount of MPs found in freshwater environments was not expected. Their possible sources are unclear at this moment.

Key words: Marine ecosystem, freshwater ecosystem, sediments, oceanic island, fish, lobsters, shrimps.

Microplásticos encontrados en el Parque Nacional Isla de Cocos, Patrimonio de la Humanidad, Costa Rica

RESUMEN. Los microplásticos (MP), definidos como "pequeñas" piezas de plástico < 5 mm, se han encontrado en casi todos los hábitats marinos del mundo, y los estudios han demostrado que podemos encontrarlos en la superficie del océano, en la columna de agua, en el fondo marino, en la costa, en la biota y en la interfaz atmósfera-océano. Este estudio tuvo como objetivo evaluar los ambientes marinos y de agua dulce de la Isla de Cocos, Costa Rica, en el Océano Pacífico, mediante el muestreo de sedimentos y biota para determinar la presencia y abundancia de este contaminante. Las muestras de sedimento fueron superficiales y pesaron un kilogramo cada una. Para el muestreo de peces de agua dulce y camarones, se realizó una captura no selectiva con redes pequeñas en ríos

*Correspondence:
karol.ulate.naranjo@una.ac.cr

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con acceso por tierra. Para el muestreo de peces marinos se utilizaron cañas de pescar, y para langostas se utilizaron jaula y buceo con escafandra autónoma. Se encontraron plásticos en todo tipo de muestras: 93% de sedimentos marinos, 32% de sedimentos de agua dulce, 20% de peces de agua dulce, 15% de camarones de agua dulce, 27% de peces marinos y 51% de langostas marinas. Al igual que muchos informes en todo el mundo, se esperaba encontrar MP en las muestras marinas, y se concluyó que las corrientes oceánicas, las actividades turísticas y los aparejos de pesca desechados por actividades de pesca ilegal podrían ser fuentes de contaminantes marinos. Por el contrario, no se esperaba la cantidad de MP encontrada en ambientes de agua dulce. Sus posibles fuentes no están claras hasta el momento.

Palabras clave: Ecosistema marino, ecosistema de agua dulce, sedimentos, isla oceánica, peces, langostas, camarones.

INTRODUCTION

Anthropogenic litter on the marine environment has significantly increased over the recent decades. Initially described in the marine environment in the 1960s, marine litter is nowadays commonly observed across all oceans (Bergmann et al. 2015). Plastic, the main component of litter, has become ubiquitous and sometimes represents up to 95% of the waste that accumulates on the shorelines, the sea surface and the seafloor. Together with its breakdown products, mesoplastics (5-25 mm) and microplastics (< 5 mm) (GESAMP 2019) have become more abundant in the marine environment than any other pollutant (Bergmann et al. 2015).

The term ‘plastic’ is used in many fields and has different definitions. For the purpose of this study, it is defined as a sub-category of the larger class of materials called polymers, including thermoplastics and some thermoset materials such as polyurethane foams, epoxy resins, and some coating films that are generally counted within the category of ‘plastics’ in marine debris (GESAMP 2015). Traditionally, the term microplastic (MP) has been widely adopted as a generic form for ‘small’ pieces of plastic (< 5 mm) (Andrady 2011; Gewert et al. 2017; Miller et al. 2017; Herrera et al. 2018; Froese and Pauly 2021).

There are primary and secondary sources of MPs. The difference relies on whether particles are originally manufactured to be < 5 mm (primary) or if they are a result from the breakdown of larger pieces of plastic (secondary) (GESAMP 2015; UNEP and GRID-Arendal 2016). Some primary MPs include production pellets/powders and engineered plastic microbeads used in cosmetic formulations, cleaning products, and industrial abrasives. On the other hand, secondary MPs are degraded and then fragmented, such as textile fibers, tire dust, and water bottles, among others (UNEP and GRID-Arendal 2016).

Visual characterization is the most used method for the identification of MPs (using size, type, shape, and color as criteria). The minimum resolution is allocating into bin sizes of 100 µm (Hanke et al. 2013). Type categories are usually defined as fragments, pellets, filaments, films, foamed plastics, granules and Styrofoam. Colors are diverse and have been reported as transparent, crystalline, white, clear-white cream, red, orange, blue, opaque, black, grey, brown, green, pink, tan, and yellow (Hanke et al. 2013).

Studies on MP pollution in marine environments have received significantly greater attention compared to those of freshwater and terrestrial environments. Sampling efforts have been done in the beaches, water column, ocean surface, subtidal sediments and biota (Zobkov et al. 2018; Gola et al. 2021; Ugwu et al. 2021). However, in recent years, studies have expanded to freshwater and terrestrial ecosystems (mainly surface water and sediments) (Wong et al. 2020; Baho et al. 2021).

Global effects of MP pollution have even been documented in remote regions, such as the snow from mountains (Free et al. 2014; Napper et al. 2020), the Arctic (Bergmann et al. 2019) and arctic polar waters (Bergmann and Klages 2012; Lusher et al. 2015), and deep-sea sediments (Van Cauwenberghe et al. 2013), to mention a few. In high-altitude remote areas, the presence of MPs is mostly due to atmospheric transportation (by wind, storm, or rain); therefore, MPs can easily reach different isolated ecosystems (Allen et al. 2019) and spread into terrestrial systems (Rilling 2012). Also, remote coastal areas, where local pressures are low or even absent, are expected to be less affected by environmental pollution (Zhao et al. 2015; Çomakli et al. 2020). Additionally, there is increasing evidence of MP pollution in remote coral reef systems (Imhof et al. 2017; Ding et al. 2019; Tan et al. 2020). These remote systems are considered healthy ecosystems now facing the potential threats of the emerging MP contaminants as well. Despite this, little is known about key issues such as the spatial distribution of MPs within these remote uninhabited areas or the possible sources and input pathways of MPs into these regions (Tan et al. 2020).

The research of MPs in Costa Rica is just beginning, and the information is scarce. Currently, Costa Rica has only two studies of MPs in marine organisms. The first report of MPs was in a sample of 30 sardines from the Family Clupeidae, with *Opisthonema libertate* (filter feeders' fish) from the Pacific coast. Researchers detected MPs in all individuals with an average of 36.7 pieces per fish, 79.5% were microfibers and 20.5% were other types of plastic particles (Bermúdez-Guzmán et al. 2020). In another study a year later from the Pacific coast, 27 individuals from seven different species of fish from higher trophic levels were sampled. Eighty-nine percent of the fish had MPs, with an average of 3.75 MPs per fish and 93% of these particles were microfibers. Also, they sampled 29 benthonic carnivorous crabs (*Callinectes arcuatus*), 76% of which had MPs with 2.64 MPs per crab, and 93% microfibers (Astorga-Pérez et al. 2022).

Moreover, Cocos Island National Park is the only oceanic island of Costa Rica, located 535 km from the Costa Rican Pacific coast, far away from any populous city. The highest elevation point is Cerro Iglesias with an altitude of 575.5 m above sea level. The island is covered by tropical rainforest and its average annual precipitation varies between 4,500 to 6,000 mm (Alfaro 2008). Herrera (1985) suggested that the high precipitation is because the island is strongly influenced by the north-south movement of the Inter-Tropical Convergence Zone. The island is drained by three main watersheds: the Genio River, which flows north and empties into Wafer Bay; the Iglesias River, which flows from north to south and empties into Iglesias Bay; and the Lièvre River watershed, which flows from east to west and empties into Chatham Bay. In addition, the hydrographic network of this island is formed by permanent rivers and streams, which differentiates it from other oceanic islands located in the Eastern Tropical Pacific, such as those from the Galapagos archipelago, which are more arid (Bergoeing 2012; Gutiérrez-Fonseca et al. 2013).

Furthermore, Cocos Island is regarded as one of the few effective Marine Protected Areas around the world and it has become famous because of its large aggregations of pelagic species (Naranjo-Elizondo and Cortés 2018). Apart from a few park rangers and some facilities provided for regular visitors such as researchers and volunteers, the island is almost inhabited (Díaz-Bolaños et al. 2012). Because of this, plastic residues in the National Park could be generated from daily human activities (e.g. cooking, cleaning, among others), the majority of which happen at the Wafer base. Besides this local production of plastic residues, the confiscation of illegal fishing gear around the island and marine debris carried by marine currents to the coasts of Cocos Island National Park could also be important sources of plastic pollution (SINAC 2017).

Because Cocos Island is a remote island with low anthropogenic influence, the aim of this research was to assess the presence and abundance of MPs and estimate differences between terrestrial and aquatic ecosystems regarding this pollutant. This study examined sediments and biota from both ecosystems.

MATERIALS AND METHODS

Sampling site

Cocos Island is part of the Cocos Marine Conservation Area, a site managed by the Costa Rican National System of Conservation Areas (Sistema Nacional de Áreas de Conservación, SINAC). This island with a surface area of 24 km^2 possesses an extensive diversity of ecosystems at both land and marine levels, where the cloud forest and coral reefs predominate (Díaz-Bolaños et al. 2012; Alvarado et al. 2016). It has abundant fresh water with numerous streams that flow along the coast surrounding the two main rivers of the island (Genio River and Iglesias River). The legal category of this protected area only allows diving activities, while hunting, fishing and any other activity threatening the different ecosystems' health are banned (González-Andrés et al. 2020).

Two field expeditions were conducted to obtain samples. During the first expedition (June 18th to July 7th 2019 under Permission 2019-I-ACMC-08) most of the samples of sediments, freshwater fish, freshwater shrimps and marine fish were collected (Figure 1). Later, in the second expedition (October 3th to October 15th 2020 under Permission 2020-I-ACMC-08) the majority of the marine lobster samples were collected.

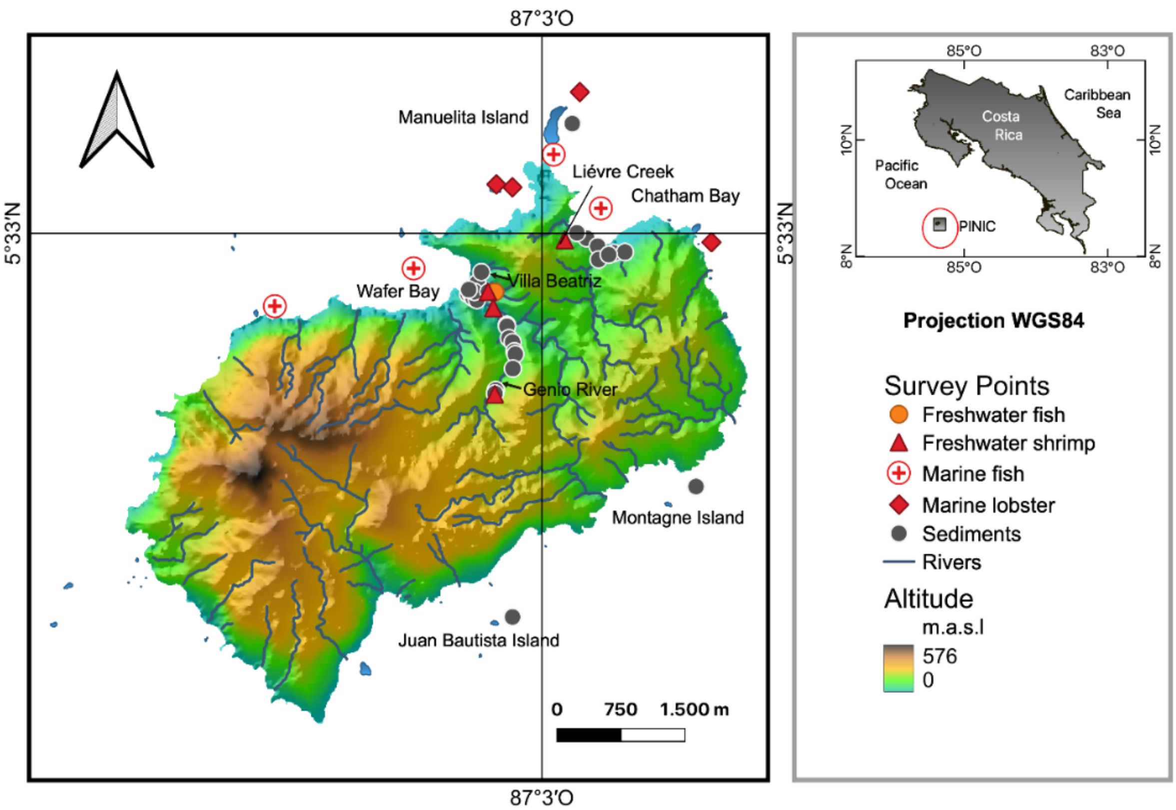

Figure 1. Collection sites and sample types from Cocos Island (m.a.s.l = meters above the sea level).

Sample collection

Marine and freshwater sediments

All sediment samples were superficial and weighed one kilogram each. They were sampled by taking approximately the top 5 cm of the sediment in a 50 50 cm square with a clean stainless steel hand trowel and stored in metal containers previously washed with distilled water. Metal containers were stored in freezers at 0 °C prior to processing (Herrera et al. 2018).

Freshwater organisms

All freshwater fish species were indistinctly caught with small nets in the rivers, which were accessed by land. Fishing nets were also used at two more sites, Liévre creek and Genio River, for freshwater shrimps sampling.

Marine organisms

Fishing rods were used for the marine fish sampling at the north side of the island due to unfavorable environmental conditions on the south side of the island. Captured freshwater and marine fish were placed in coolers with ice for transportation to the processing point in the island. All instruments were sterilized with alcohol and quantitatively washed with distilled water. Tables were covered with bags and cotton garments to avoid cross-contamination. Collected organisms were weighed (g) and measured (total body length in cm) (Table 2). Subsequently, lobsters and fish were dissected to remove the entire gastrointestinal tract (GIT) following the procedures described by Boerger et al. (2010) and Lusher et al. (2013). Extracted GITs, composed by stomach, intestine, liver, pancreas, and pyloric cecum were weighed separately and preserved in glass containers with 70% alcohol. In the case of freshwater shrimps, the digestive system could not be extracted due to their small size, therefore, the exoskeleton was carefully removed and the whole animal was preserved in glass containers with 70% alcohol.

Sample processing

In order to prevent and/or reduce potential contamination from external sources, such as airborne fibers, the laboratory workspace was frequently cleaned, and work was performed in a laminar airflow cabinet, particularly for preparing solutions, sieving and filtrating, when possible. In addition, glassware was washed thoroughly, oven-dried and covered with aluminum foil when not in use.

Sediments

For sediment samples, a density separation and filtration method using aqueous solutions was performed. The aim of this process was to utilize density differences to separate different types of polymers from organic and inorganic natural particles such as the sediment, sand or silt particles (Kershaw et al. 2019). One kilogram of every sediment sample was mixed with a NaCl solution (1.2 g cm^{-3}) and stirred for at least 2 h for sand samples, and 24 h for silty sediment samples (Hidalgo-Ruz et al. 2012; Qiu et al. 2016; Martin et al. 2017; Enders et al. 2020). After agitation, the sample was allowed to settle (covered with aluminum foil) for 24 h, allowing denser constituents to sink and less dense particles to float or to remain in suspension. After 24 h, the supernatant was filtered with a Büchner funnel and passed through a 10 µm retention glass fiber filter paper. In most cases, a triplicate was required while filtering since the presence of silt made the process difficult. Filter papers were removed in a laminar cabin and stored in sealed Petri dishes prior to examination under a stereo microscope.

Organisms

Freshwater shrimps and GITs of lobsters, marine and freshwater fish, were chemically digested to extract MPs. Extraction was carried out according to the method described by Cole et al. (2014), Kühn et al. (2017), and Bessa et al. (2019). A solution of 10% KOH to digest the organic matter was added. The volume of the liquid did not exceed 50% of the total volume of the Erlenmeyer (250 or 500 ml). To obtain a dissolved solution, Erlenmeyers were covered with aluminum and placed in an oscillating incubator at 60 °C at 300 rpm for 24 h. Subsequently, the digested content from the chemical process was sieved through a 60 µ stainless steel sieve and transferred to a clean Petri dish. The excess of water was evaporated in an oven at 45 °C for 30 h. Glass Petri dishes were covered with aluminum foil with small holes to allow water to evaporate and prevent possible airborne plastic contamination (Enders et al. 2020).

Identification and validation of microplastic

All particles were identified, measured, and photographed using a stereo microscope OPTIKA SZ-ST2 with image analysis system AMSCOPE MU1000 Camera with AMPSCOPE software. Plastic particles < 5 mm were classified as MPs; if their size was > 5 mm they were excluded from the analysis (Andrady 2011). They were also classified by type as fibers (elongated), fragments (irregular pieces), pellets or films (thin and transparent) and categorized by their color (Hidalgo-Ruz et al. 2012; Qiu et al. 2016; Martin et al. 2017; Enders et al. 2020). Knots (fragments of fishing nets between 5-25 mm) were photographed and counted into the frequency of occurrence but not considered in the calculation of the average MPs/lobster, since they are not considered MPs.

Quality control of experiments

Glassware, plastics and dissection tools were rinsed three times with distilled water to reduce possible contamination (Li et al. 2015; Lusher et al. 2015). Tap water, saline water and sodium hydroxide were filtered with a 1 mm glass fiber filter before use, and samples were covered with aluminum foil to prevent any kind of pollution. To prevent contamination by airborne MPs, sample handling was performed in a laminar flow cabinet (Zhang et al. 2017; Mason et al. 2018; Oßmann et al. 2018; Wang et al. 2018). Negative controls (Jabeen et al. 2017) were carried out during sodium hydroxide treatments, observation, identification and validation of MPs, resulting in a total of 22 controls. All particles identified in these controls were fibers, and any similar particles found at sediments and tissues samples were excluded from the analysis.

Statistical analysis

The number of MPs data in different organisms and ecosystems were not normally distributed according to the Shapiro normality test at 95% of confidence. Therefore, a Mann-Whitney Test for two independent samples were performed to determine differences of MPs abundance between marine and freshwater sediments, marine fish and lobsters, freshwater fish and shrimps, marine and freshwater fish, and marine lobsters and freshwater shrimps. Statistical analyses were performed using R Statistical Software (R Core Team 2020).

RESULTS

All types of samples resulted positive for the presence of MPs: 93% of marine sediments, 32% of freshwater sediments, 27% of marine fish, 20% of freshwater fish, 51% of marine lobsters, and 15% of freshwater shrimps. In addition, two types of MPs were observed: fibers and fragments (see Supplementary Material for the most representative images of MPs found). In marine lobsters, pieces bigger than > 5 mm were found, photographed, classified as fibers and knots but excluded from statistical analysis (Appendix, Figure A1).

Contamination from the laboratory was detected from 22 contamination controls. An average

2.3 ± 2.0 plastic/control was determined. Particles found in negative controls were fibers with sizes > 5 mm. These particles could be derived from the air pollution in the laboratory, although many sources of contamination were avoided. Fibers that were consistent in shape and color in the controls were not considered in any sample.

Sediment samples

Marine sediment samples were collected from sandy beaches (14 samples) and shallow water (4 samples) at different locations. In addition, 14 freshwater sediment samples were collected from Genio River, Villa Beatriz creek, and Liévre creek (Table 1). All sediment samples were taken at depths less than 10 m. A frequency of occurrence of 93% was obtained in marine ecosystems with an average of 3.35 ± 4.30 MPs per sample, and 32% in freshwater ecosystems with an average of 1.00 > 1.47 MPs per sample (Figure 2). Mann-Whitney Test showed a significantly higher quantity of MPs in marine ecosystems ($p = 0.025$) when comparing it to the freshwater ecosystems.

Organism samples

For marine fishes, a total of 31 Jordan's snappers (*Lutjanus jordani*) from the Family Lutjanidae were caught. For freshwater fishes a total of 30 organisms from four families (Gobiidae,

Table 1. Locations and sediment textures of sampling sites located in marine and freshwater sediments of Cocos Island.

Location site	Sediment texture	Number of samples
Wafer Bay	Sandy beach	10
Liévre creek Bay	Sandy beach	4
Montagne Island	Shallow water	1
Manuelita Island	Shallow water	1
Juan Bautista Island	Shallow water	1
Liévre creek Bay	Shallow water	1
Genio River	Muddy sediments	10
Villa Beatriz creek	Muddy sediments	3
Liévre creek	Muddy sediments	1

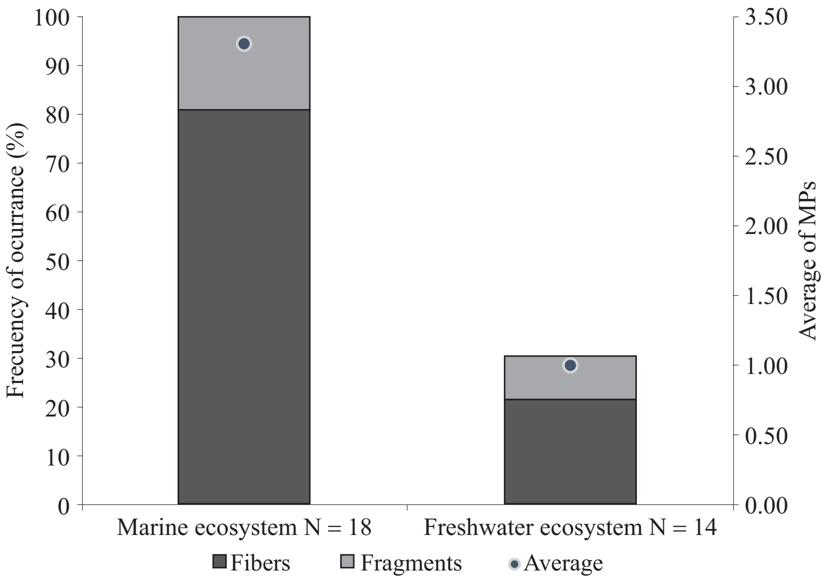

Figure 2. Comparison of microplastics (MPs) in sediment samples between marine and freshwater ecosystems from Cocos Island, Costa Rica.

Mugilidae, Eleotridae and Gobiesocidae) were captured. Species from each family were respectively: eleven organisms *Sicydium cocoensis*, nine organisms *Dajaus monticola*, six organisms *Eleotris picta* and four organisms *Gobiesox fulvus.* During the first expedition, 14 green spiny lobsters of the species *Panulirus gracilis* (Family Palinuridae) were captured with traps. Because of high predation by whitetip reef sharks in the traps, in the second expedition the lobsters were captured directly through scuba diving, resulting in 39 lobsters from the same Family Palinuridae: 11 *Panulirus gracilis* and 28 *Panulirus penicillatus.* Also, a total of 32 shrimps of the Genus *Macrobrachium* sp. were captured. Table 2 describes the characteristics of the captured organisms.

A frequency of MPs occurrence of 27% was obtained in marine fishes, with an average of 1.37 ± 0.51 MPs per organism (Figure 3). A total of 11 MPs were found, 82% of them were fibers, while only 18% were fragments (Table 3). Ninety percent of the MPs had a mean size < 3 mm and the main color was black, followed by red and blue. In the case of freshwater fishes, a frequency of occurrence of 20% was obtained with an average of 1.16 ± 0.40 MPs per organism. A total of 7 MPs were found, 57% of them were fibers, while 43% were fragments. All sizes of the MPs were < 3 mm and the main color was blue, followed by black and red.

In marine lobsters, a frequency of occurrence of 51% was obtained with an average of 1.42 ± 0.75 MPs per organism. A total of 18 MPs were found, 56% of them were fibers, while 44% were fragments. Eighty-three percent of the MPs found in marine lobsters had mean size < 3 mm, but they were the only organism with three pieces bigger than > 5 mm (11.25 mm, 10.22 mm, and 9.85 mm), identified as knots but excluded from the analysis, since they are not considered MPs

Table 2. Morphometric characteristics of the organisms collected in the Cocos Island National Park to determine the presence of microplastics (MPs) in their tissues.

Fish species	N	Characteristics	
		Average of body weight (g)	Average of total length (cm)
Marine fishes			
Lutjanus jordani	30	567 ± 109	35 ± 2 (31.6-81.5)
Freshwater fishes			
Dajaus monticola	9	5.9 ± 3	13 ± 6 (7.5-23.5)
Eleotris picta	6	205 ± 168	25 ± 6 (19.5-34.1)
Gobiesox fulvus	4	14 ± 3	11 ± 4 (8.4-17)
Sicydium cocoensis	11	13 ± 9	9 ± 2 (5.3-11.5)
Marine lobsters			
Panulirus gracilis	23	302 ± 87	10 ± 1 (7.8-12)
Panulirus penicillatus	11	650 ± 340	11 ± 3 (7.3-19)
Freshwater shrimps			
Macrobrachium sp.	39	4 ± 6	5 ± 2 (3.5-13.3)

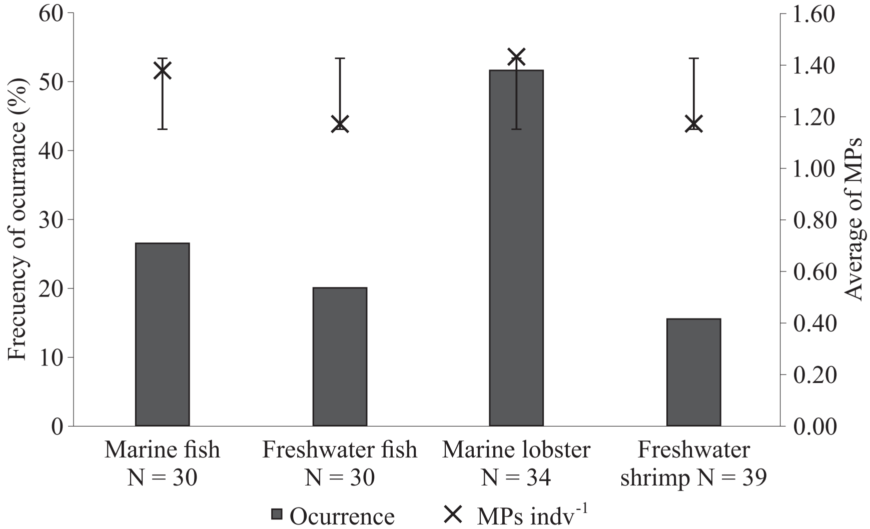

Figure 3. Microplastics (MPs) found in marine and freshwater organisms at Cocos Island National Park, Costa Rica.

Table 3. Types, sizes, and colors of microplastics found in the biota of Cocos Island National Park, Costa Rica.

Characteristic	Classification	Marine fish (%)	Freshwater fish (%)	Marine lobster (%)	Freshwater shrimp (%)
Form*	Fibers	82	57	56	100
	Fragments	18	43	44	0
Size	< 1mm	45	57	83	67
	1-3 mm	45	43	17	33
	3-5 mm	9	0	0	0
Color	Red	36	14	28	33
	Black	45	29	22	17
	Blue	18	43	22	33
	Others	0	14	28	17*

*Even though other categories of forms were considered in this research, such as fiber, fragment, films and pellet, only two types of MPs were found (fibers and fragments). Predominant colors were blue, black and red. Category 'other' included green, transparent and white.

(Appendix, Figure A1). The main color of MPs in marine lobsters was red. In freshwater shrimps, the frequency of occurrence was 15% with an average of 1.16 ± 0.40 MPs per organism. A total of 6 MPs were found, 100% of them were fibers. Mean size of the MPs were all < 3 mm and the main color was blue and red, followed by black.

Microplastics were observed in all organisms. The number of MPs between marine and freshwater fish was not statistically significant (Mann-Whitney Test, p = 0.4895). The abundance of plastics by items/individual was significantly higher in marine lobsters than in freshwater shrimps (Mann-Whitney Test, p = 0.0056).

DISCUSSION

Cocos Island National Park is sparsely populated and far away from the continent and big cities; despite that, MPs were found at both freshwater and marine ecosystems. Furthermore, higher frequency and quantity of MPs were found in marine sediments compared to freshwater sediments. In the marine environment, the presence of MPs has been demonstrated in a wide diversity of regions and concentrations because of their persistence and long-range transportation by wind, rainfall and/or currents. Particularly, beaches and subtidal sediments appear to function as sinks for MPs (Duis and Coors 2016; Katare et al. 2021; Nammalwar 2021).

Studies of the surface circulation in the South Pacific Ocean have shown an accumulation of debris in the eastern-center region of the South Pacific Gyre (Martinez et al. 2009). Also, large debris concentrations were found just north of the North Pacific Transition Zone within the North Pacific Subtropical Convergence Zone (Pichel et al. 2007). Cocos Island is located between these two giant gyres (North Pacific and South Pacific), which could be important sources of MPs. In fact, the California Current, which can carry materials from the North Pacific Gyre, is the possible source of MPs of the north coast of Costa Rica (Johnson et al. 2018).

A lower abundance of MPs was expected in samples from terrestrial ecosystems, but an occurrence of 32% was determined in sediments, 20% in freshwater fish, and 15% in shrimps. According to Lwanga et al. (2016), the majority of MPs particles entering the freshwater are primarily from i) secondary plastics generated by the breakdown of larger plastic items (single-use packing, tires, fibers from synthetics fabrics and road paint particles); and ii) effluent discharges from wastewater and sewage. Additionally, it was determined that population density and quality of waste management can be established as the key anthropogenic factors affecting the presence and abundance of MPs in the freshwater environment (Free et al. 2014; Lwanga et al. 2016). Nevertheless, due to the low density of people that inhabit the island (SINAC 2017) and the pristine origin of the island's rivers, the sources of plastic contamination in freshwater ecosystems remain unclear.

One possible source are MPs from atmospheric transportation by wind and/or storms. The tropical area where the island is located receives large volumes of annual rainfall, and its humidity comes from the Pacific Ocean (Alfaro 2008). Recently, it has been demonstrated that MPs can travel within the air as ‘urban dust’ (Dehghani et al. 2017; Dris et al. 2017), which usually originates from road dust from tires, paint particles, or fibers from synthetic textiles (GESAMP 2015; Dris et al. 2017; Horton et al. 2017). Also, studies on atmospheric fallout in Paris, France (Dris et al. 2016) and Dongguan, China (Liqi et al. 2017) suggest an atmospheric MPs conveyance and subsequent deposition. Remote and pristine areas are also affected. Research in a remote area of the Pyrenees mountains provided evidence of direct atmospheric fallout of MPs deposition (Allen et al. 2019). Additionally, the detection of MPs in glacier surface snow collected from an isolated area from human impact on the Tibetan Plateau, indicated that MPs can be transported over long distances (Zhang et al. 2021).

The majority (63%) of the MPs found in organisms were classified as microfibers, this result is consistent with those of Celik (2021), Makhdoumi et al. (2021) and Pan et al. (2021). According to the literature, microfibers are considered as the major marine pollutant throughout the world. Some authors estimate a million tons of coastal synthetic fabric waste entering the ocean each year, affecting different marine ecosystems. They also point out that there is an urgent need for development of cost-effective and efficient remediation technologies, legislative action towards the source and public awareness (Mishra et al. 2019; Singh et al. 2020).

The present study analyzed two groups of organisms in marine and freshwater ecosystems: fish and crustaceans, whose different feeding habits, behaviors and habitats, play important roles in the ingestion of debris. Indeed, an increase in the abundance of plastics will also increase the bioavailability of this pollutant to other organisms (Boada et al. 2015; Jabeen et al. 2017). The marine fish analyzed (*Lutjanus jordani*) are usually found over hard bottoms in the inshore reef areas and are carnivorous, feeding mainly on invertebrates and smaller fish (Fischer et al. 1995; Bussing and López 2005). The freshwater fish were caught in shallow and turbulent rivers, and the different genus of the species found are reported to feed on zooplankton, algae, and small benthic invertebrates (Bussing 1998). Freshwater fish caught are considered 'benthonic fish' and the MPs found in these organisms could be related to heavy plastics in the benthic zone, unlike marine fish that consume plastics floating in the water column. Marine lobsters and freshwater shrimps are both benthic macroinvertebrates associated to rocky bottoms, hence they are more exposed to the debris deposited on the sea bottom or stream bed (Naranjo 2011; Figueroa and Mero 2013; García-Guerrero et al. 2013).

It could be predicted that marine lobsters will have a higher exposure to debris than freshwater shrimps. Naranjo-Elizondo and Cortés (2018) found anthropogenic debris at Cocos Island, between 200 and 350 m depth, from which 60% of the items were plastics from local boats and fishing gears. Fishing gears comprised lost lines and most of fishing debris observed in contact with fish or crabs (Naranjo-Elizondo and Cortés 2018). These authors' concern about the possible plastic ingestion by different organisms eventually confirmed it with the present study. Nylon fishing knots found inside marine lobsters' digestive system were > 5 mm (11.25 mm, 10.22 mm, and 9.85 mm), and were in the process of conversion to MPs. Only a higher number of items per individuals was determined in marine lobsters versus freshwater shrimps. This coincides with the result of a higher number of MPs in marine sediments versus freshwater sediments. This last could be influenced by the feeding mode of each organism and the abundance of MPs in the habitat in which they are found.

Statistical analyzes did not detect differences in the type of plastic particles ingested by marine and freshwater organisms. Therefore, investigation regarding types and abundance of debris in both ecosystems should continue. However, strategies that involve behavioral change, removing/cleaning-up and mitigation measures to reduce the inputs of plastics from land or sea bottom sources are being taken to tackle this complex problem (Ogunola et al. 2018).

CONCLUSIONS

It was conclusive that both marine and freshwater ecosystems are being affected by MP particles. It is important to continue investigating the sources and impacts of MPs in both ecosystems to find solutions that can be effectively implemented. Although the sources of MPs in the freshwater ecosystem are so far unclear, transportation of MPs from seabirds or by wind are possible hypothesis that should be investigated in future assessments.

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APPENDIX

Pieces between 5-25 mm were found in three of the marine lobster's digestive systems. Figure A1 shows the particles identified as fishing knots made from nylon fibers. Besides the knots, a considerable amount of nylon fibers was also extracted and counted. Lobsters had 81, 14, and 37 nylon fibers resulting from the fragmentation of the knots, respectively.

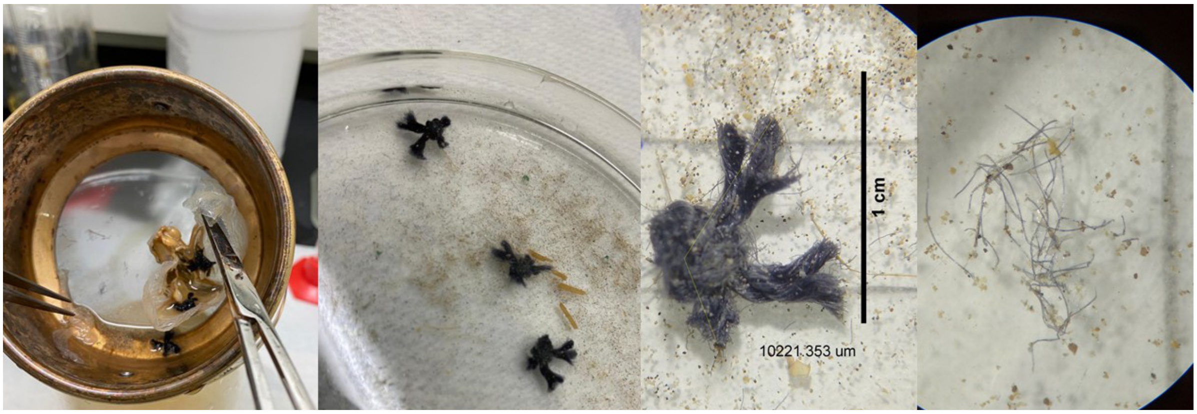

Figure A1. Mesoplastic extracted from a marine lobster digestive system.