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The Ecological Implication of Microplastic in Crabs from a Tropical Lagoon: Ingested Microplastic in Mud Crab *Scylla serrata*

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Abstract: Large plastic items in the environment are degraded into tiny pieces known as microplastics (MPs). MP contamination in tropical lagoon ecosystems poses a significant pollution threat. The mud crab, *Scylla serrata*, is an important crustacean in the tropical lagoon, valued as a key source of edible seafood in Asia and Europe. The potential MPs of one hundred samples were examined using the stereomicroscope for characterisation, and further analysis was conducted using µ-FTIR. A total of 1157 MPs were found in the gills and gastrointestinal tract. The mean abundance (±SD) of MP in mud crabs was 11.57 ± 6.29 items/individual. MPs were detected in both tissues, displaying a variety of colours. Transparent MPs dominated the gills at 43.9%, while blue microplastics were prevalent in the gastrointestinal tract at 32.8%. The filament (fibre) was the most prominent MP type found in the gills and gastrointestinal tract. The collected MPs from both tissues were categorised into four size ranges: 0.05–0.25 mm and 1.00–5.00 mm were the common size ranges in the gills and gastrointestinal tract, respectively. The prominent polymer type was rayon. These findings provide considerable proof of MP contamination in the mud crab species *Scylla serrata* and its implications for food security.

Keywords: *Scylla serrata*; tropical lagoon; µ-FTIR; microplastic; mud crab; rayon

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1. Introduction

Anthropogenic activities are producing more and more waste, which is filling up landfills at an alarming rate [1]. Many waste dumps are composed of plastic [2]. Plastic is a kind of synthetic polymer that is made by using a broad assortment of chemicals added to the monomers derived from oil or gas [3]. PE and PP are the most abundant types of plastics, due to their high production, with PE leading the global market and PP following closely behind [4]. Currently, the worldwide plastic industry yields approximately USD 600 billion in earnings each year [5]. Plastic consumption in Asia currently stands at 20 kg per person and is expected to rise steadily shortly [6]. Plastic possesses distinctive characteristics like lightweight, strength, heat resistance, aesthetic appeal, and low thermal conductivity [7]. These qualities contribute to their extensive utilisation across 79 industrial sectors [8–13].

The accumulation of plastic waste in the environment is a major pollution threat [14]. Waste electronics, electrical equipment, and other life vehicles are expected to become a prominent type of plastic in waste [15]. Due to inland waterways, tidal, and wastewater outflows, mismanaged waste is released into the aquatic ecosystem [16–19]. Several factors [20–24] contribute to reducing the molecular weight of large plastics [25]. Minute plastic particles within the size range of 1 μm to 5 mm are called microplastics (MPs) [26]. Tiny particles at the microscale are employed in the industrial sector and classified as primary MPs [27]. Secondary MPs emerge because of the degradation of large plastic objects [28]. MPs pose environmental risks, but the degree of threat varies depending on their shape and size [29]. MPs are globally distributed and travel long distances [30]. Because of the small size range of MPs, microorganisms can thrive by utilising MPs as habitats [31]. MPs are widely distributed in the marine environment because of their low density, nature of floating and incessant properties [32,33]. MPs of primary origin are directly introduced into the environment as small pellets, used as abrasives in both industrial and domestic settings [34]. Additionally, facial cleansers, commonly used by millions, contribute to the release of MPs [35,36]. Consequently, MPs can be detected in several ecosystems [37–53].

As a vital aquatic ecosystem, lagoons serve as multifunctional environments and support a wide array of organisms through various processes [54–56]. Tropical lagoons are inland water bodies separated from the ocean by a physical barrier [57]. Nearby urban areas contribute to numerous non-natural pressures on tropical lagoons [16,58]. These lagoons are crucial for economic activities including fisheries, tourism, agriculture and leisure [59], as well as other services [60–67]. Lagoons can serve as conduits for transporting plastic waste from terrestrial to marine ecosystems [68]. Numerous studies provide evidence for global MP contamination in lagoon ecosystems [69–73]. MPs in sediments are vertically distributed in the lagoon because of the bioturbation process [74]. This bioturbation process of the lagoon encompasses burrowing, ventilation and movements of benthic fauna [75,76]. MPs can move vertically within water columns and penetrate deep into benthic sediments [77,78]. The vertical distribution is significant for assessing the impact of the MPs on the biota, and this distribution acts as a transport medium for the MPs [79–81].

MPs can interact with flora and fauna in the lagoons [72,73,82,83]. Some habitats within lagoons are known to trap and accumulate microplastics such as seagrass [84,85] and mangroves [86,87]. Lots of studies also evidence MP contamination in organisms inhibiting lagoons, including crabs [88,89], shrimp [90,91], bivalves [92–94], oysters [95,96] and fish species [97–99]. The extent of this interaction depends on animals consuming MPs, influenced by the feeding, human activities and pollution levels in their habitat [36]. Due to their small size, comparable to that of plankton, MPs can be consumed by various aquatic organisms [100] regardless of their distinct feeding strategy, including filter feeders [101], deposit feeders [102] and detritivores [103]. MPs can carry and amass chemical additives tainted in water due to their elevated surface area-to-volume ratio [104]. Also, consuming MPs can elevate oxidative stress, alter metabolic functions, impact immune defences and affect reproductive rates in organisms [20]. MP presence in the intestinal tract of the organisms can be translocated to the circulatory system [105].

Decapod crustaceans, including crabs, are particularly affected by microplastics, with several studies reporting large numbers and tangles of plastic in their gastrointestinal system [106–109]. Mud crabs *Scylla serrata* inhabit the lagoons and estuaries in tropical and subtropical countries [110] which are situated in the Indo-West Pacific region [111]. The excellent nutritional value and irresistible taste of mud crabs have made them highly palatable and in global demand [112–114]. The mud crab, *Scylla serrata*, significantly contributes to the local Sri Lankan seafood industry through commercial harvesting [115]. The report of the Ministry of Fisheries states that the average monthly household consumption of crab was 7.6 g [116]. Crabs play a role in essential functions [117,118]. Mud crabs disturb sediments in ecosystems by burrowing and digging in the soil. They are highly efficient scavengers, consuming a diverse range of organisms [119,120].

The present study aimed to quantify and describe the physical characteristics of microplastics (MPs) present in the mud crab species *Scylla serrata*, found in the Negombo Lagoon. This research focused on identifying the morphological features of the MPs, including their shape, size, type, and colour, specifically in the gills and gastrointestinal tract of the mud crab. Additionally, the study sought to determine the polymer types of the MPs found in the mud crabs. The findings of this research will contribute to future studies in the Negombo Lagoon, Sri Lanka.

2. Materials and Methods

2.1. Study Area and Sampling Locations

This study carried out a sprawling brackish water lagoon ecosystem between North Latitude 7°10′ and East Coast Latitude 79°50′ situated in Negombo, Sri Lanka following on from [121]. This largest brackish water ecosystem is one of the coastal lagoons extending alongside the western shoreline of Sri Lanka. The northern end of the lagoon extremity links with the Indian Ocean via a narrow channel, while its southern end is linked to the Muthurajawela marsh [64]. The Negombo Lagoon is a thriving ecosystem, supporting a rich diversity of species, therefore benefiting local communities [64]. It has been exposed to pollution through several activities including fishing [65], poor management of waste dumps [66] and the X-Press Pearl ship disaster [67]. The Negombo Lagoon serves as a home for several aquatic organisms. Among the 142 species in the lagoon, 112 are edible comprising 100 species of finfish, 4 types of molluscs, 7 species of shrimp, and 1 type of crab [64]. In Negombo, the mud crab *Scylla serrata* significantly contributes to the local seafood industry through commercial harvesting [115]. Hence mud crab samples were collected from five fishing grounds (L1 to L5) in the Negombo Lagoon (Figure 1). The samples were transported in a cool box to the laboratory.

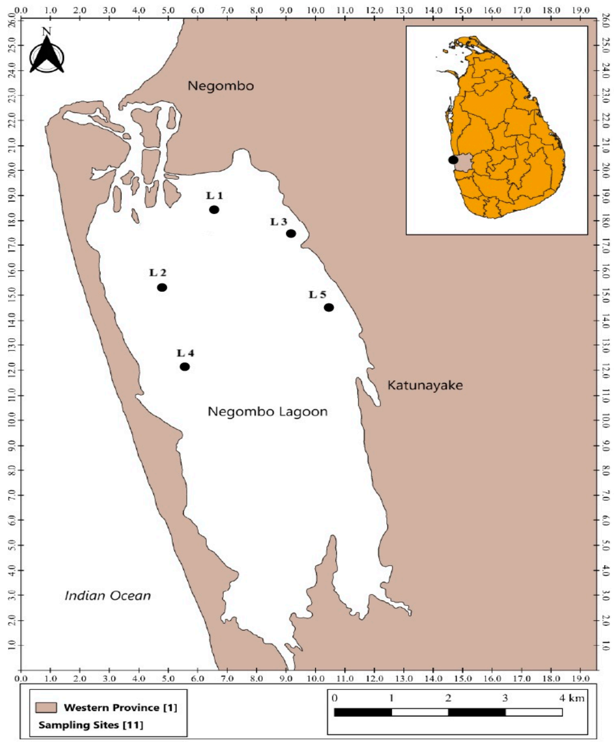

Figure 1. Sampling locations in the Negombo Lagoon, Sri Lanka.

2.2. Sample Collection, Preparation, and Digestion

A total of one hundred (n = 100) samples of mud crabs were collected from November 2022 to June 2023 within five fishing grounds (twenty crabs in each location) inside the Negombo Lagoon. The weight and carapace width of the crabs were measured using an electrical scale (BSA224S-CW) and a vernier calliper. The gills and gastrointestinal tract were dissected on a metal tray. The weight of the gills and gastrointestinal tract was recorded. The dissected and separated samples were stored in the glass bottles, and to prevent contamination, the glass bottles were covered with aluminium foil. The sample underwent soft tissue digestion with a volume of 10% KOH (Sigma-Aldrich, Saint Louis, MO, USA) that was added at least twice the volume of the sample. The solution was heated to 55 ± 5 °C and allowed to undergo overnight digestion in an oven (GALLENKAMP SANYO OMT, Lough-borough, UK) [106].

2.3. Quality Control

To prevent possible contamination during the treatment process, KOH and distilled water were vacuum-filtered through a support membrane filter with a pore size of 1.2 µm before being utilised. To avoid contamination, all laboratory instruments, including the metal tray, forceps and dissecting scissors, were thoroughly rinsed with distilled water before utilisation. And before storing the samples in the glass bottles, they were cleaned using a bath sonicator. Samples were covered by using Aluminium foils extensively to minimize exposure to airborne contaminants. A blank sample was used in each set of samples (n = 10) to quantify airborne contamination.

2.4. Sample Filtration and Microscopic Analysis

Following the digestion process, clear and slightly yellow supernatant was filtered under vacuum through glass filament microfilter papers with a pore size of 1.2 µm (Whatman Grade GF/C Glass Microfiber Filter Papers, 1.2 µm, 21 mm Diameter Circles, Binder-Free). The filters were stained with Nile Red (Sigma-Aldrich, Saint Louis, MO, USA) and examined using a stereo microscope (Euromex StereoBlueSB.1902-P, Euromex Microscopen by, Arnhem, The Netherlands). Every visually identified microplastic item was photographed and categorized based on colour, morphology and size (length) using the image-focus alpha software. The quantity and variety of microplastics present in the gills and gastrointestinal tract were documented.

2.5. Micro FTIR Analysis

A subset of visually identified particles was analysed with a Lumos II µFTIR (Bruker, UK). Using an MCT detector and ATR-µFTIR analysis, 32 scans were collected in reflectance mode between 4000 and 500 cm^{-1} at a resolution of 4 cm^{-1}. A 60% match against polymer libraries (ATR-FTIR-library vol. 1–4; Bruker Optics ATR-Polymer Library; IR-Spectra of Polymers, Diamond-ATR, Geranium-AT and IR-Spectra of Additives, Diamond-ATR) was required for the confirmed polymer type, in line with previous standards [122].

2.6. Statistical Analysis

To assess the prevalence of MPs in both the gills and gastrointestinal tract of mud crabs, initial evaluations were calculated to determine normality using the Shapiro–Wilk test and homogeneity of variance using Levene's test. To determine statistical significance, a p-value threshold of 0.05 was set. The data failed to meet the criteria for parametric statistics, as indicated by $p < 0.05$ in the Shapiro–Wilk test and homogeneity of variance using Levene's test. As a result, the Wilcoxon test was applied to examine variations in the abundance of MP presence between the gills and gastrointestinal tracts. A one-way analysis of variance (ANOVA) was applied to assess differences in MP abundance between the different sampling locations. A Spearman's rank-order correlation test was conducted to determine the relationship between crab weight and MP abundance. A confidence interval of 95% was used for all tests.

3. Results

3.1. MP Abundance in Mud Crab at Different Locations

The average net weight of the one hundred mud crabs collected from all five locations was 149.25 ± 67.9 g. The average cephalothorax length and width were 97.51 ± 16.09 mm and 67.69 ± 10 mm, respectively. Twenty (n = 20) crab samples were collected from each of the five locations. The mean abundance of MP in the five sampling locations was expressed as the number of items per individual (items/individual) and items per gram (items/grams) (Table 1). The results revealed that the crabs collected from L3 had the highest mean abundance of MPs, with a value of 12.50 ± 7.40 items/individuals. L2 had the highest mean abundance of MPs with a value of 0.10 ± 0.04 items/grams. The mean abundance of MPs in mud crabs was lower at L5 (10.60 ± 4.60 items/individuals) and L1 (0.07 ± 0.03 items/grams) than at the other sites (Figure 2). There was no significant difference between these five locations ($p > 0.05$).

Table 1. Characteristics of the mud crab *Scylla serrata* from five locations.

Location	L1	L2	L3	L4	L5
Sample size (n)	20	20	20	20	20
Average net weight of crabs (g) ± SD	169.32 ± 79.09	132.17 ± 74.62	149.85 ± 62.42	142.85 ± 49.01	151.57 ± 71.70
Average cephalothorax width of crabs (mm) ± SD	69.35 ± 11.74	65.8 ± 9.71	67.95 ± 9.53	67.25 ± 7.69	68.10 ± 11.51
Average cephalothorax length of crabs (mm) ± SD	100.82 ± 19.36	94.15 ± 14.2	97.15 ± 12.02	98.95 ± 19.92	96.45 ± 14.27
Mean abundance (item/grams) ± SD	0.07 ± 0.03	0.10 ± 0.04	0.09 ± 0.05	0.08 ± 0.05	0.08 ± 0.04
Mean abundance (item/individual) ± SD	11.15 ± 5.10	11.15 ± 5.10	12.50 ± 7.40	11.30 ± 8.10	10.60 ± 4.60

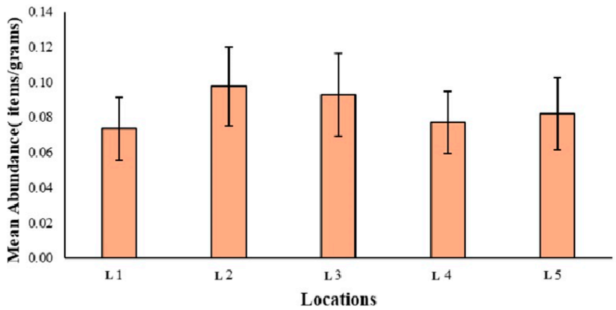

Figure 2. MP abundance of the five sampling locations.

3.2. Abundance of MPs

This study explored the occurrence of MPs in both the gills and gastrointestinal tract of *Scylla serrata*, a mud crab species. A total of 1157 MP items were detected from total mud crab samples (n = 100). This investigation revealed the presence of MPs in all 100 evaluated samples. The mean abundance (±SD) of MP in mud crabs was 0.09 ± 0.05 items/g. This value significantly exceeds the mean abundance observed in many crabs from diverse locations globally (Table 2). MPs presence in the gills and gastrointestinal tract of the mud crab was significantly different ($p < 0.05$) with a mean abundance (±SD) of 2.12 ± 1.56 items/g in the gastrointestinal tract and 0.99 ± 0.89 items/g in the gills. Moreover, a greater proportion of MPs (63%) were in the gastrointestinal tract compared to the gills (37%). This study aimed to investigate whether MP consumption increases with the body weight of the crab species. The results indicated a weak positive correlation between the weight and MP count of mud crabs, which was not statistically significant (rs = 0.139, $p = 0.169$) (Figure 3).

Table 2. The contamination of diverse crab species worldwide with MPs varies based on geographical locations.

Name of Species	The Main Size of MPs in Gills and GIT	The Main Colour of MP (GIT)	The Main Colour of MP (Gills)	The Main Type of MP in Gills and GIT	Total Number of MPs	Items/Individual MP Abundance	Study Area	References
Mangrove Crab, ***Ucides occidentalis***	0.002–0.25 mm	Clear	Clear	Filament	921	11.35 ± 7.91	Local Markets in Tumbes, **Peru**	**Aguirre-Sanchez et al., 2022 [26]**
Ghost Crab, ***Ocypode quadrata***	NA	Black and Blue	NA	Filament	NA	1 to 158	Grussai Beach Arch, **Brazil**	**Costa et al., 2019 [123]**
C. maenas* and *E. sinensis	2.1–3.0 mm	Clear	Clear	Filament	874	1 ± 0.82–11.35 ± 7.91	Thames Estuary at Erith Rands, **UK**	**McGoran et al., 2020 [106]**
Chiromantes dehaani	1–20 µm	White	Transparent	Filament	NA	0.39 ± 2.83	The Beibu Gulf of the **South China Sea**	**S. Zhang et al., 2021 [124]**
Blue Swimming Crab, ***Portunus pelagicus***	0.09 µm up to 38.6 mm	Red	NA	Filament	216	0.73 ± 1.4	Wonnapha Coastal Wetland, **Thailand**	**Kleawkla, 2019 [125]**
Wild Crabs, ***P. trituberculatus, C. japonica, D. japonica, M. planes***	<1000 µm	Black–Grey	Black–Grey	Filament	631	5.17 ± 4.43	Yellow Sea and East China Sea, **China**	**T. Zhang et al., 2021 [126]**
Intertidal Crab, ***Chiromantes dehaani***	<1000 µm	Dark Colours	Dark Colours	Filament	592	1.48 ± 0.45	Intertidal zone in Chongming Island, Yangtze Estuary	**Wu et al., 2023 [127]**
Mud Crab, ***Scylla serrata***	0.0002–0.25 and 1–5 mm	Blue	Transparent	Filament	1157	11.57 ± 6.29	Negombo Lagoon in **Sri Lanka**	**Present Study**

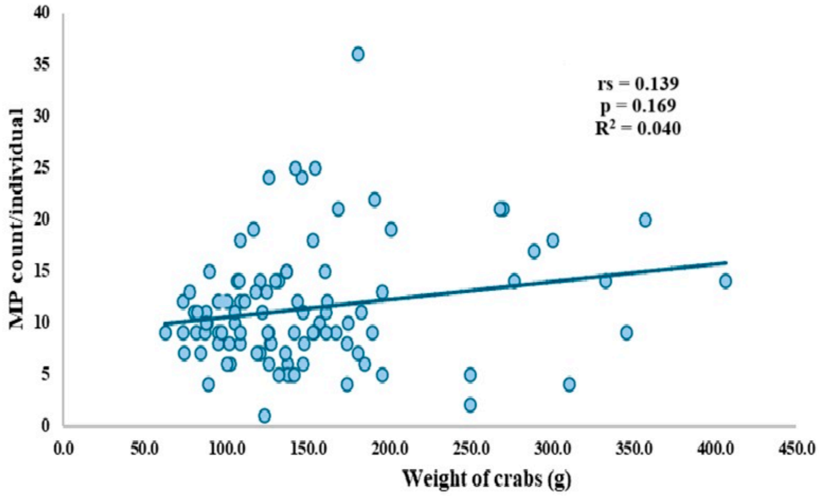

Figure 3. Spearman correlation between crab weight and MP abundance (R^2 = 0.040).

3.3. Characteristics of MPs

3.3.1. Size of MPs

The MPs compiled from both the gills and the gastrointestinal tract were sorted into four different size categories, including 0.05–0.25 mm, 0.25–0.50 mm, 0.50–1.00 mm and 1.00–5.00 mm. This investigation demonstrated that MP particles with dimensions 0.05–0.25 mm were the most prevalent in the gills of mud crabs, comprising 34.39% of the total. The 1.00–5.00 mm size range was the most prevalent in the gastrointestinal tract (Figure 4).

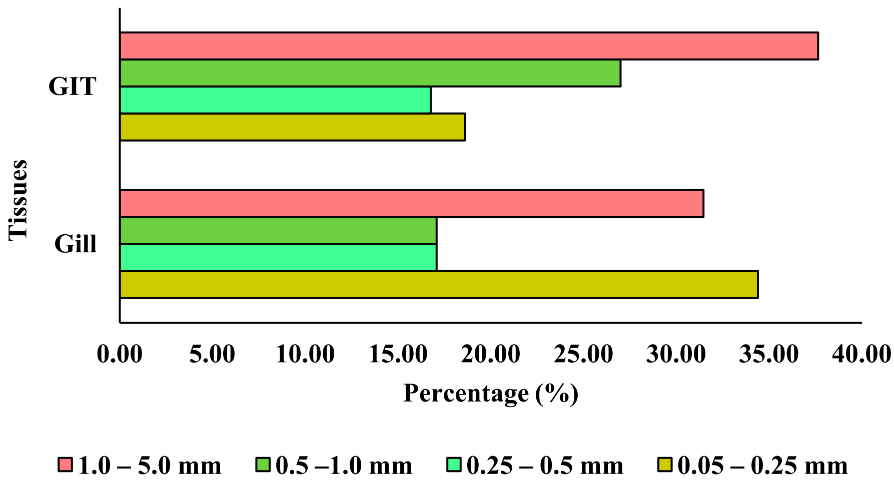

Figure 4. MP abundance in different sizes in both the gills and gastrointestinal tract (GIT).

3.3.2. Types and Colours of MPs

In mud crab samples, approximately 80% of the items comprised filaments, while the remaining 20% comprised films and fragments. The MP analysis of this study revealed the presence of MPs in both tissues, exhibiting a range of colours, including blue, transparent, red, black, yellow, green, white, and purple (Figure 5). MPs identified in both the gills and gastrointestinal tract were sorted based on their shapes as filaments (fibre), films and fragments. The predominant type of MP detected in both the gills and gastrointestinal tract was filaments, accounting for 63.60% and 85.70%, respectively (Figure 6). In the gills, transparent (43.90%) was the dominant colour, while blue (32.80%) prevailed in the gastrointestinal tract. In both the gills and the gastrointestinal tract, the prevalent MPs consisted of blue filaments, transparent films and transparent fragments (Figures 7 and 8).

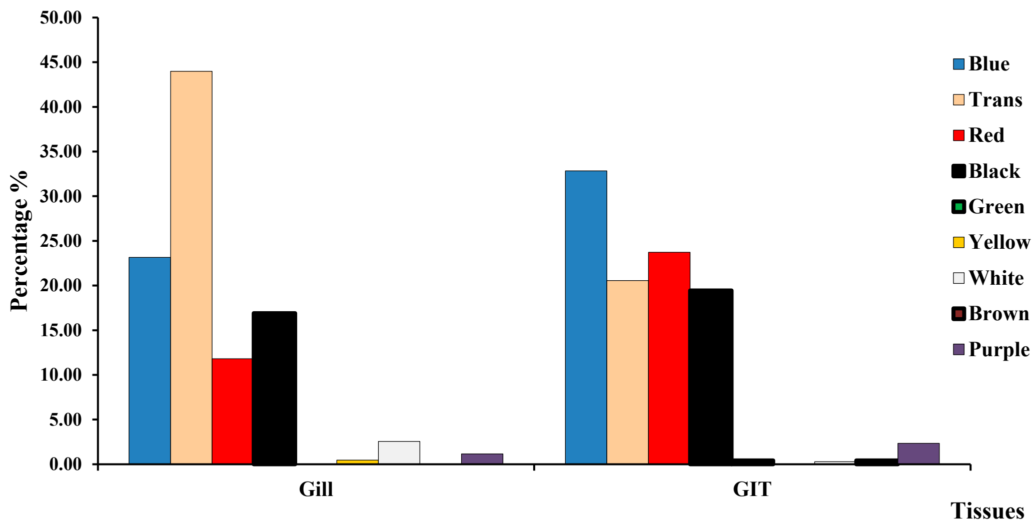

Figure 5. MP abundance according to the colour in both the gills and gastrointestinal tract (GIT).

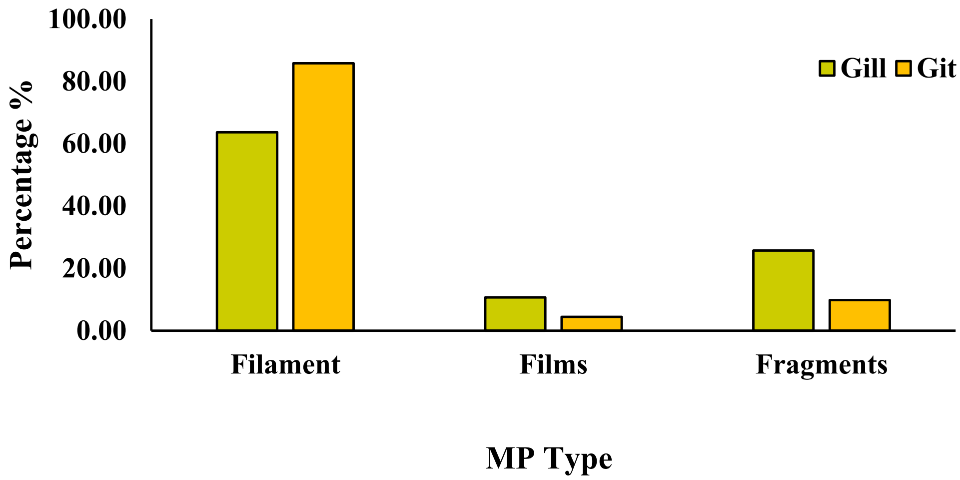

Figure 6. MP abundance according to the type in both the gills and gastrointestinal tract (GIT).

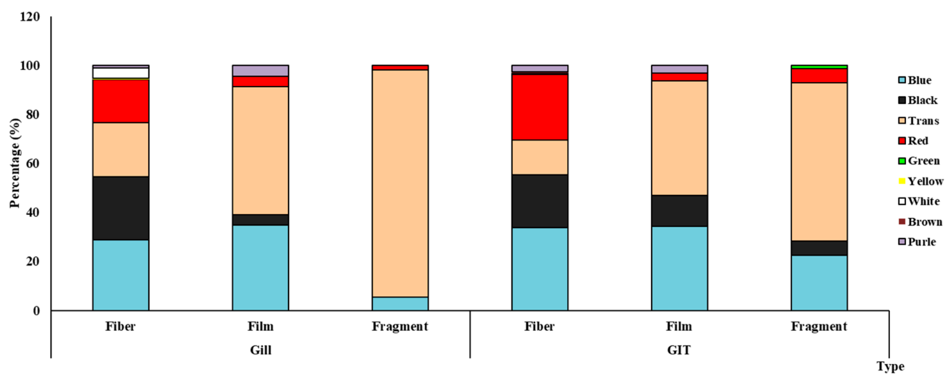

Figure 7. MP abundance according to the colour and type in both the gills and gastrointestinal tract (GIT).

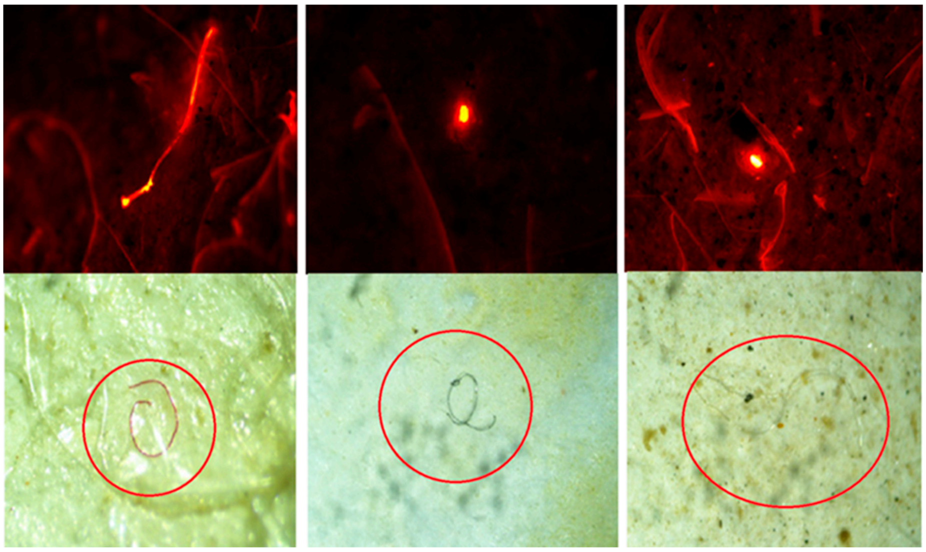

Figure 8. Images of MPs found from the gills and gastrointestinal tract of *Scylla serrata* blue light with Nile red and normal light.

3.4. Polymer Characterisation of MPs

Out of the total crab samples, polymer characterisation was carried out in only 27 (27%) samples. µ-FTIR analysis revealed that 74% of visually identified items were synthetic, and 26% were classified as anthropogenic. The analysis further unveiled that the synthetic polymers were rayon (51%), polyester (PES) (11%), polypropylene (PP) (5%), paint (5%), polyethylene (PE) (1%), polyethylene terephthalate (PET) (1%) and a rayon–cotton blend (13%). On the other hand, the anthropogenic polymers consisted of cellulose, cotton and rubber (Figures 9 and 10).

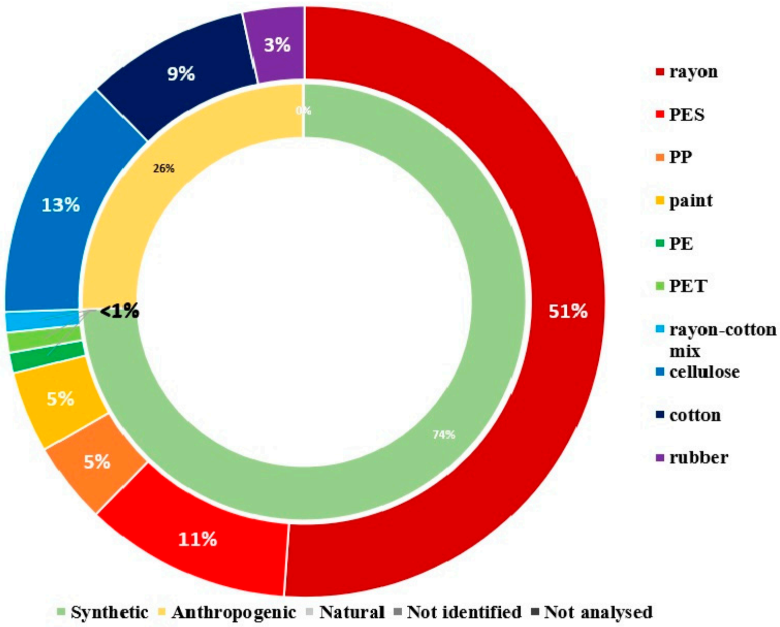

Figure 9. Polymer characterisation of MPs.

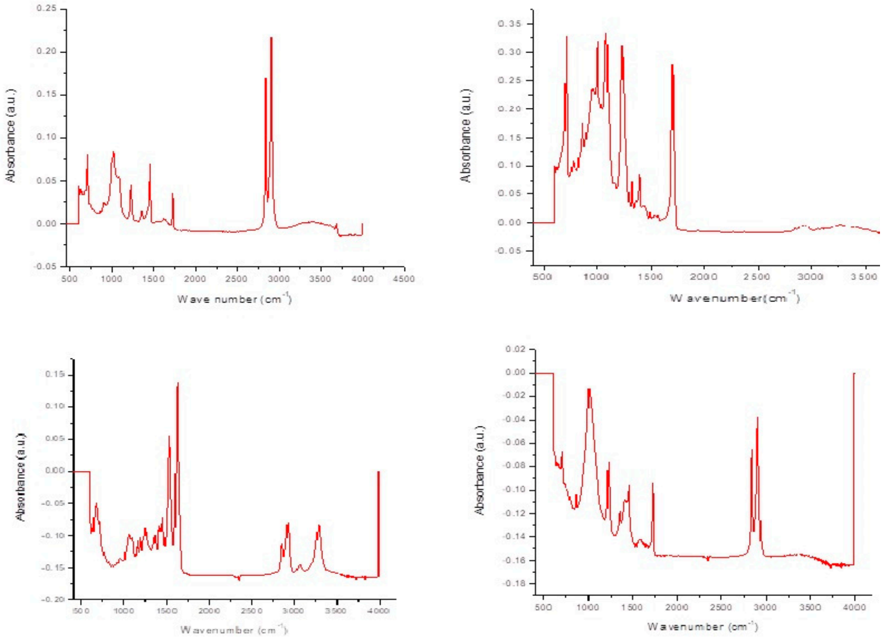

Figure 10. µ-FTIR spectra of the main polymers found in the gills and GIT of the mud crab *Scylla serrata* inhabiting the Negombo Lagoon, Sri Lanka.

4. Discussion

This study investigated the presence of MPs in the gills and digestive tract of the mud crab species *Scylla serrata* inhibited in the Negombo Lagoon, Sri Lanka. The results presented demonstrate that microplastics are highly abundant in the biota of the lagoon and may be negatively affecting the mud crabs living there. This study had several limitations. During the research period, fluctuations in waste pollution occurred due to tidal ventilation. Additionally, in certain months, crab yields were lower, which made it challenging to collect crabs of consistent sizes. Samples were gathered from five fishing grounds, each with varying physical and chemical conditions. Furthermore, FTIR analysis was performed on only 27 of the total crab samples.

In this study, the mean abundance (±SD) of MP in mud crabs was 11.57 ± 6.29 items/individual. According to the other studies of crabs, this value is notably high. The crab species *Chiromantes dehaani* inhabiting the Beibu Gulf of the South China Sea (0.39 ± 2.83 items/individual) [124], Blue Swimming Crab, *Portunus pelagicus* in Wonnapha Coastal Wetland, Thailand (0.73 ± 1.40 item/individual) [125], Intertidal crab, *Chiromantes dehaani* in Intertidal zone in Chongming Island, Yangtze Estuary (1.48 ± 0.45 items/individual) [127] and Wild crabs, *P. trituberculatus*, *C. japonica*, *D. japonica* and *M. planes* in the Yellow Sea and East China sea, China (5.17 ± 4.43 items/individual) [126]. The results of the present study are in line with estimates from crabs in urbanised estuaries in the UK [106] and those collected from markets in Peru [26]. This suggests that some regions or aquatic systems are more prone to contamination, and therefore the local wildlife are more likely to ingest microplastics. Indeed, Negombo Lagoon is contaminated by MPs in its water (2.46 ± 1.13 items m^{-3}), sediment (62.33 ± 45.16 items/kg) [128] and mangrove habitats [72].

The outcome of this study was anticipated, considering the numerous industrial and anthropological activities occurring in the lagoon vicinity [129]. The proximity of the fish market to the Negombo Lagoon leads to waste and carbonic by-products being directly released into the lagoon, posing a potential pollution threat [130]. Furthermore, food waste and untreated sewage from hotels and densely populated urban areas are also directly discharged into the lagoon [131]. The results of the correlation test of this study indicate that there is no relationship between the crab weight and the MP count of the mud crabs.

The findings of this study showed that there was a notably lower abundance of MPs in the gills compared to the MPs found in the digestive tract, likely attributed to the cleaning mechanism present in crab gills. This mechanism aids in the removal of foreign objects from the gill chambers, reducing the likelihood of MP particles entering the gills [132]. Typically, mud crabs are benthic organisms closely linked with other creatures in the benthic environment [133]. Crab species, including *S. serrata*, dwell in soil and sediment habitats. Crabs exhibit a unique behaviour of pulling decaying plant material into the sediment, where they leave it for a few weeks before consuming it [134]. Crab burrows serve as traps for MPs, leading to an elevated presence and detection rate of these particles in the deeper sediment layer instead of solely the surface layer [135]. Indeed, Iribarne et al. [136] reported that burrowing crabs ingest more MPs and McGoran et al. [106] reported that the burrowing *Eriocheir sinensis* ingested more MPs than *Carcinus maenas*. Hence, the burrowing habits and dietary content of mud crabs offer substantial evidence supporting the existence of the highest abundance of MPs in their digestive tract. The mud crabs consume food along with mud particles, and they capture sediments during burrowing, potentially leading to the uptake of MPs into the digestive tract.

The most prominent type of MP in this study was filaments, which typically emerge as the predominant MP type detected in crab species around the world (Table 2). Recent investigations conducted on the Negombo Lagoon offer substantial proof regarding the prevalence of filaments (fiber) as the predominant form of MPs [73,99]. The prevalence of filaments among various types of MPs in the environment is mainly due to their lightweight nature, which enhances their ability for long-distance transportation in the ocean [137]. Synthetic filaments have become widespread globally due to their various applications, including packaging, textiles, and fishing gear, resulting in nearly 60% of filaments being consumed [29]. Additionally, their low weight contributes to their accumulation on the surface of water, where they directly engage with the ventilation systems of crabs [26].

When marine organisms ingest tiny plastic components like microfilaments, it often leads to physical complications such as digestive tract blockages [138]. When crabs become ensnared in fishing nets, they utilise their large claws to cut through the nets to escape, leading to the ingestion of filament-based fishing lines into the digestive tract of crabs [126]. The primary pathways for filaments to enter aquatic ecosystems include the use of fishing gear like nets and ropes, as well as the improper disposal of industrial and household waste [30]. The analysis of MPs in this study indicated the presence of MPs in both tissues, displaying a variety of colours. The predominant type of MP observed in the gills was transparent, consistent with findings from various studies worldwide. For instance, research on Mangrove Crab, *Ucides occidentalis* in Tumbes, Peru [26], *Chiromantes dehaani* in the Beibu Gulf of the South China Sea [126] and *C. maenas* and *E. sinensis* in Thames Estuary at Erith Rands, UK [106]. However, some studies showed dark colours as a prominent colour of MPs in the gills such as Wild crabs, *P. trituberculatus*, *C. japonica*, *D. japonica* and *M. planes* in the Yellow Sea and East China Sea, China [126] and Intertidal crab *Chiromantes dehaani* in the intertidal zone in Chongming Island, Yangtze Estuary [127]. MPs that are suspended on the water's surface tend to be lighter in colour, often appearing transparent or white [124].

The colouration of MPs in the digestive tract is influenced by the feeding habits and other ecological traits of the organisms [30] and organisms tend to ingest microplastics that share similar colours to their natural food sources [139]. The colour of microplastics (MPs) might resemble that of potential prey, leading visual predators to inadvertently consume MPs [124]. According to the findings of this study, the digestive tract of the mud crab contains blue MPs most prominently. This result is similar to the findings of other studies. Conducted on the ghost crab, *Ocypode quadrata* in Grussai Beach Arch, Brazil [123], the Intertidal crab, *Chiromantes dehaani* in the intertidal zone in Chongming Island, Yangtze Estuary [127] and Wild crabs, *P. trituberculatus*, *C. japonica*, *D. japonica* and *M. planes* in the Yellow Sea and East China Sea, China [126].

The MPs found in both the gills and digestive tract were classified into four size ranges. MPs within a smaller size range of 0.05 to 0.25 mm made up 34% of the particles found in the gills and 19% in the digestive tract of *S. serrata*. The mud crabs utilise their gills for respiratory purposes during the ventilation of surrounding water, creating a potential route for MPs to enter the gills [140]. Due to their lower velocity, smaller MPs tend to undergo vertical transportation [141]. As water containing MPs flows through the gills, the intricate structure of the gills facilitates the entrapment of MPs [26]. Most of the MPs in the digestive tract are in the size range of 1.00–5.00 mm.

The polymer types of MPs detected in the gills and digestive tract included Rayon, PES, PP, paint, PE, PET and a rayon–cotton blend. Comparison with other studies reveals consistency in the polymer types of microplastics found in crabs. The main polymers found in the crabs of the aquaculture pond in the Yangtze River Delta of China were PET, polystyrene (PS), PE, PP and polyamide (PA) [46]. The mangrove Crab, *Ucides occidentalis* in Tumbes, Peru contained both PET and ethylene–vinyl acetate (PEVA) [26]. The most common polymer types of *C. maenas* and *E. sinensis* in Thames Estuary at Erith Rands, UK were PP and PES [106]. In this study, Rayon was the prominent type of polymer. Rayon serves as the overarching term referring to fibres, yarns and fabrics produced from regenerated cellulose [142]. Conventional laundering of textile garments has been identified as a primary method for releasing synthetic textile fibres into water bodies [143].

Due to their elevated high surface area-to-volume ratio, MPs function as a toxic agent. Consequently, the ingestion of MPs by organisms leads to the provision of stimuli, nutrient dilution and ultimately reduced growth within their body [144]. Multiple trophic transfer investigations offer proof that crabs uptake MPs through their ventilation process and the ingestion of contaminated prey animals [145]. MPs may be transferred through the digestive tract of crabs and eventually accumulate in the hepatopancreas [105]. Larger MPs cannot be transported through the gut lining and can be retained in the foregut for 120 h (5 days), which is longer than the passage of regular food items [145]. The deposition of MPs in the digestive tract of crabs has the potential to negatively affect their health by diminishing nutrient absorption and feeding activity [146]. The retention time of the MPs in the gills was greater than that in the digestive tract because the gills have a large surface area, and the gill lamellae provide many folders [140]. The presence and buildup of MPs in the gills could impair osmoregulation and respiratory function by interfering with gas exchange processes occurring within the gill chambers. Water within the gill chamber is recycled and evaporates, leading to a concentration of MPs within the gill chamber as it trickles down towards the top of the legs [147].

The accumulation of MPs in the crabs not only impacts their health, but may also facilitate the transfer of MPs into the ecosystem via the food chain, given that crabs are a major dietary component for humans [124]. The presence of MPs at a lower trophic level, including plankton, copepods, and slaps, leads to the transfer of MPs to the higher trophic level [148]. Hence, edible crustaceans such as crabs, lobsters, crayfish and prawns, along with various edible fish species that encompass pelagic, demersal and reef classifications offer substantial evidence of the widespread occurrence of MPs [146]. Exposure of MPs to the human body can occur through the consumption of contaminated foodstuff. MPs, which are consumed by small fish and bivalves, are frequently concentrated in the gastrointestinal tract, and eating their entirety increases the likelihood of introducing MPs into the human diet [149]. But even if the digestive tract and gills are removed, chemical pollutants associated with plastic may still be transferred. Humans are adversely impacted by the various harmful effects caused by MPs. MPs offer a conductive surface for the proliferation of microorganisms, and they function as a medium for transmitting pollutants [31]. Also, MPs could adhere to external surfaces; as a result, they can clog the digestive tract and reduce mobility along with disruption of the energy metabolism, harm to genes, oxidative stress, strain liver and inflammation.

5. Conclusions

The current study reported evidence of MPs in both the gills and gastrointestinal tract of the mud crab *Scylla serrata* inhabited tropical lagoons. The existence of MPs in the mud crabs was facilitated by the plastic debris present in the sediments and water of the lagoon. The primary route for microplastics to enter the gastrointestinal tract is through the burrowing habits and dietary intake of the mud crab, as evidenced by the significantly greater abundance of microplastics found in the gastrointestinal tract compared to the gills. The most prominent polymer type found in the mud crab was rayon which comes from fibres, yarns and fabric products. Additionally, the most common MP type was filaments (fibres). These types originate from the waste dumps associated with the fisheries and other household activities. The abundance of mud crabs inhabiting tropical lagoons was greater than that of crabs found in wetlands, the sea and estuaries. While this study establishes a preliminary benchmark for the rapid detection of microplastics in mud crabs, these findings offer a further understanding of contamination levels and raise concerns regarding food security. Certainly, with negative impacts on growth and reproduction linked to plastic pollution and its associated chemicals, commercial populations could suffer, negatively impacting local fishing communities.

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