Journal of
Marine Science and Engineering

MDPI

Article

Depth Profiles of Microplastic in Sediment Cores in the Mangrove Area of Kuala Gula Mangrove, Malaysia

Che Abd Rahim Mohamed [1], Aqilah Nur Shahruddin [1], Siriporn Pradit [2,*], Pei Sun Loh [3], Thongchai Nitiratsuwan [4], Thawanrat Kobkeatthawin [5], Prakrit Noppradit [2], Thi Phuong Quynh Le [6], Chantha Oeurng [7], Ty Sok [7], Choon Weng Lee [8,9], Chui Wei Bong [8,9], Xixi Lu [10], Gusti Z. Anshari [11], Selvaraj Kandasamy [12] and Jianjun Wang [13,14,15]

1 Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia
2 Coastal Oceanography and Climate Change Research Center, Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand
3 Ocean College, Zhejiang University, Zhoushan 316021, China
4 Faculty of Science and Fisheries Technology, Rajamagala University of Technology Srivijaya, Trang 92150, Thailand
5 Center of Excellence in Catalysis for Bioenergy and Renewable Chemicals (CBRC), Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
6 Institute of Natural Product Chemistry, Vietnam Academy of Science and Technology, Hanoi 11307, Vietnam
7 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Phnom Penh 12156, Cambodia
8 Faculty of Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia
9 Institute of Ocean and Earth Sciences, Universiti Malaya, Kuala Lumpur 50603, Malaysia
10 Department of Geography, National University of Singapore, Singapore 119260, Singapore
11 Soil Science Department, Faculty of Agriculture, Tanjungpura University, Pontianak 78124, Indonesia
12 Department of Geology, School of Earth Science Systems, Central University of Kerala, Kasaragod 671320, Kerala, India
13 Jiangsu Key Laboratory of Crop Genetics and Physiology, Agricultural College of Yangzhou University, Yangzhou 225009, China
14 Jiangsu Key Laboratory of Crop Cultivation and Physiology, Agricultural College of Yangzhou University, Yangzhou 225009, China
15 Jiangsu Co-Innovation Centre for Modern Production Technology of Grain Crops, Yangzhou University, Yanzhou 225009, China
* Correspondence: siriporn.pra@psu.ac.th

check for updates

Citation: Mohamed, C.A.R.; Shahruddin, A.N.; Pradit, S.; Loh, P.S.; Nitiratsuwan, T.; Kobkeatthawin, T.; Noppradit, P.; Le, T.P.Q.; Oeurng, C.; Sok, T.; et al. Depth Profiles of Microplastic in Sediment Cores in the Mangrove Area of Kuala Gula Mangrove, Malaysia. *J. Mar. Sci. Eng.* **2023**, *11*, 1223. https://doi.org/10.3390/jmse11061223

Academic Editors: Michele Arienzo and Luciano Ferrara

Received: 19 May 2023
Revised: 7 June 2023
Accepted: 12 June 2023
Published: 14 June 2023

Abstract: Microplastics are widespread in coastal and marine environments, and sediments serve as a sink for microplastics. In this study, four sediment cores were collected from the Kuala Gula Mangrove area. The abundance of microplastics in mangrove sediments ranged from 25–130 items/kg dry weight. The highest abundance of microplastic was observed at the KG04 site near the mouth of the river. The number of microplastics by sampling site was significantly different ($p < 0.01$), with station KG04 having the highest fiber content. The dominant color of microplastics was blue, and the main shape was fiber. Rayon, cotton, Polyethylene terephthalate (PET), and azlon were observed from FT-IR, indicating that the potential sources of microplastic and fiber could come from household laundry wastewater. Microplastics tended to accumulate in deeper depths at KG01 ($p < 0.01$), whereas other stations showed no significant difference ($p > 0.05$). However, this study provides evidence that mangroves can be a trap for microplastics and can be used as baseline data for future studies.

Keywords: microplastic; sediment core; mangrove area; marine debris; aquatic pollution

1. Introduction

Over the last decades, plastic production has increased significantly and reached 367 million tons in 2020 due to increasing consumption [1]. Plastic pollution has now become a global environmental concern as an emerging contaminant in marine and coastal environments. The Malaysian economy has grown rapidly over the past 15 years, along with increasing plastic demand. It is estimated that about 62 kg per capita per year of plastic is produced for consumption in the country, which was the world's 8th largest dumper of plastic waste in 2021 [2]. According to Tan et al. [3], there are a number of reasons that contribute to plastic pollution in Malaysia, including limited recycling capacity, weak processes and law enforcement, low societal awareness, and a lack of uniformity in local monitoring.

When plastic is released into the ocean, it can break down under the influence of several environmental factors, such as physical, chemical, and biological processes, which lead to the formation of microplastics [4,5]. Microplastics are tiny plastic fragments of <5 mm diameter in size and can be classified based on their shape, size, color, and starting material [6]. They can easily spread into the environment due to their small size [7]. In addition, their small size means that microplastics could easily be ingested by various marine animals such as zooplankton [8], fish [9], shellfish [10], and shrimp [11]. The great concerns about microplastics are associated with toxic chemicals such as heavy metals [12] and persistent organic pollutants [13], which result in marine animals being exposed to these chemicals and transfer them to higher trophic levels [14]. Previous studies indicate that microplastics can be transported through the food chain and can be toxic to organisms, affecting the nervous system and leading to immune diseases, gastrointestinal exposure, cancer, and liver toxicity [15].

Mangroves are highly productive wetlands that can protect land from coastal erosion, storms, and tsunamis [16]. Mangroves are also a habitat for fauna and provide nursery grounds for various fishes and shellfish, while they also trap sediments and suspended matter in the water column [17]. In addition, it has been found that the aerial roots of mangrove trees play an important role in trapping marine plastic because of their complex root systems, which can sieve and block the flow of water and lead to the accumulation of microplastics in the sediments [18]. Ibrahim et al. [19] reported that mangrove forests in Malaysia are highly susceptible to plastic pollution due to their position at the intersection of land and ocean, where waste from nearby industrial areas is sometimes disposed of, whether intentionally or unintentionally. Additionally, a study on the prevalence of microplastics in the Kapar Mangrove Area, Selangor, reported that in 5 cm deep sediment samples at depths of 1 and 2 cm, there was an abundance of microplastics in the form of micro-sized polystyrene and plastic fragment shapes.

In addition, a study on the microplastic abundance in the Kapar Mangrove Area, Selangor, discovered that microplastics in the form of micro-size polystyrene and plastic fragments could be found abundantly in sediment samples at 1 and 2 cm of 5 cm deep soil samples [20]. Meanwhile, a review by Ibrahim et al. [19] summarized a few studies of microplastic uptake by aquatic organisms in Malaysia, which reported the presence of microplastics in sea bass [19] and hard clams [21] sampled from mangrove sites in Malaysia.

Mangrove forests are important as essential food sources and for the maintenance of the coastal fishery industry for local people in Malaysia. According to a study on the distribution of microplastics in mangrove forests in Malaysia, data is still limited. In particular, no microplastics study has been conducted in the Kuala Gula mangrove area. The authors predict the presence of microplastics based on a previous study by Pradit et al. [22] in mangrove sites in southern Thailand situated in a similar setting which could impact aquatic animals and humans who consume aquatic animals contaminated with microplastics.

Therefore, the aim of this study was to investigate the accumulation of microplastics in sediment cores at Kuala Gula Mangrove, Malaysia. The abundance of microplastics in sediment cores, including the shape, size, color, and types of microplastics, was analyzed. The novelty of this research is to provide baseline information on microplastic accumulation in a mangrove ecosystem. Our results provide relevant data for further investigation of microplastic pollution and its ecological effects in these areas, which can lead to conservation policies to manage and develop Malasia's mangrove areas in the future.

2. Materials and Methods

2.1. Study Area and Sample Collection

The Kuala Gula Mangrove Area is located in northern Perak, Malaysia. The mangrove area consists of mangrove islands, coastal mangrove forests, buffer areas which function as a stopover for various species of migratory and resident birds, and fishing villages with a total population of 7200 people on the outskirts of the mangrove area [23]. Approximately one-third of the population is involved in fishery and aquaculture industries and ongoing land reclamation in the study area [24]. As a result, the overall quality of the habitat will suffer in the future, as land-based pollutants tend to enter the mangrove sediment and water quality in the coastal area. Figure 1 and Table 1 provide information on the sample stations (KG01, KG02, KG03 and KG04). Sediment cores were collected in triplicate at the sampling stations using a hand corer (diameter 86 mm). The cores were later subsampled into 2 cm intervals of the core length. Samples were then oven-dried at about 50–60 °C for several days until they reached full dryness.

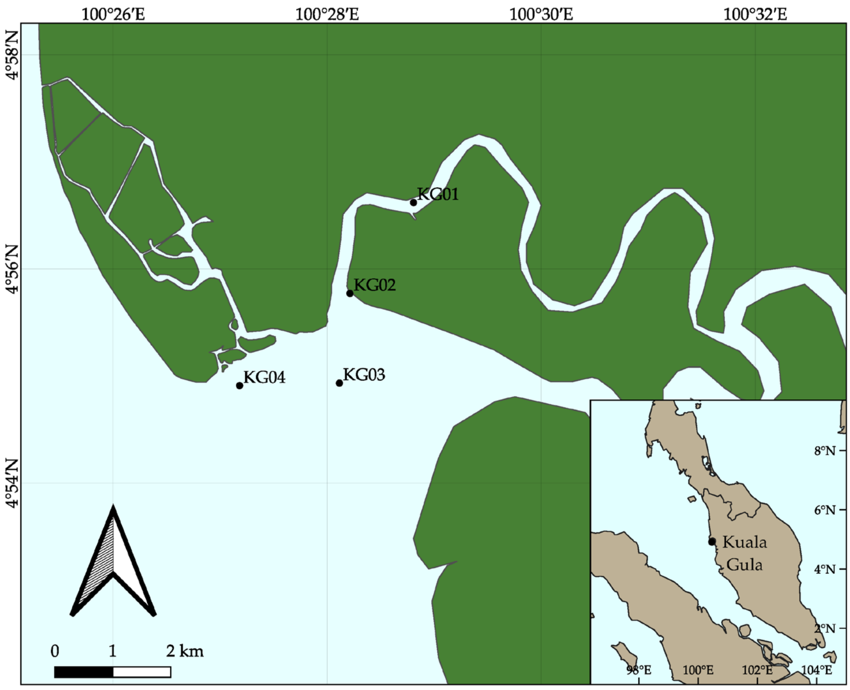

Figure 1. Map of sampling stations in the Kuala Gula Mangrove Area.

Table 1. Coordinates and site description of sampling stations in the Kuala Gula Mangrove Area.

Station	Coordinates	Site Description
KG01	04°56′37.12″ N 100°28′48.37″ E	Near the boat jetty, samples were taken close to mangrove vegetation.
KG02	04°55′46.2″ N 100°28′12.7″ E	Taken at the river mouth, where a lot of aquaculture activities are conducted.
KG03	04°54′55.9″ N 100°28′06.8″ E	Taken at the estuary, near a mudflat area. Slightly southward from the river mouth. Boats coming in and out.
KG04	04°54′54.5″N 100°27′10.8″ E	Taken at a mudflat area, facing seaward. Birds are seen foraging.

2.2. Microplastic Extraction from Sediment

In the laboratory, 20 g of dry sediment was weighed and added. The beaker was then filled with 200 mL of saturated and filtered sodium chloride (NaCl) solution. It is common practice to remove microplastics from sediments using the NaCl technique [25,26]. After mixing with a glass rod, the mixture was placed aside for one hour to allow the sediment particles to settle. Following that, 100 mL of supernatant was filtered through a new 300 µm filter cloth made from nylon. Another 100 mL of NaCl was added to the initial sample beaker and was placed aside for one hour. The process was repeated 3 times before taking the 300 µm filter cloth to another beaker and washing the contents with distilled water, and covering it with aluminum foil. Then, the sample water was filtered through the 300 µm filter cloth and was filtered again through a 20 µm filter cloth. Later, that 20 µm-micrometer filter cloth was placed in another beaker, the contents washed with distilled water, and the beaker was covered with aluminum foil. After that, 10 µm of H_2SO_4 and H_2O_2 each were added to the samples and left to heat on a hot plate (controlled temperature of not more than 75 °C) to digest the contents. Then, 6 g of NaCl reagent powder was added to the sample beakers and left for 24 h at room temperature. The samples were then filtered using another clean set of 300 µm filter cloth and glass microfiber GF/C and were placed in individual petri dishes. The petri dishes were then placed in a hot oven at 50 °C for 3 h to let the samples dry completely before viewing under the microscope.

2.3. Microplastic Identification

Under a stereo microscope, the microplastics in the filter paper were visually identified using the physical and morphological characteristics of the plastic particles [22]. This technique made use of a Leica EZ4 W Stereomicroscope with a magnification of 10–40 times. The Leica Application Suite was used to capture the particle photos. There was no bias in the light reflection from the microscope since the filters were entirely dry. The microplastic particles were categorized by their type (fiber, fragment, and others such as microbeads, film foam, and pellets), size (<500 µm, 500 μm^{-1} mm, and >1 mm), and color (blue, black, red, white, and other). All these categories of microplastic were observed and recorded. A few microplastic particles were randomly chosen from each sample and placed in a clean petri dish in order to analyze the properties of the polymer. To distinguish the microplastic polymers, Fourier Transform Infrared Spectroscopy (FTIR) (Spectrum Two with Spotlight 200i, Perkin Elmer, Waltham, MA, USA) was employed. The spectral range was defined at 4 cm^{-1} resolution and 4000 cm^{-1} to 400 cm^{-1} wavelength. The microplastic spectrum found in the sediment samples was compared to the spectrum library of each type of polymer.

2.4. Contamination Control

Extensive precautions were taken during the separation process of the sediment samples to prevent any contamination when handling and processing them. To ensure that the experiment was as contaminant-free as possible, cotton lab coats and polymer-free gloves were used [27,28]. Distilled water and saturated NaCl were filtered before use in the experiment to prevent microplastic contamination. Clean filter papers were used during the filtration procedure to avoid contamination. Throughout the experiment, aluminum foil was used to shield the samples in the beaker from any potential airborne contaminants. All the tools and glassware used for the analysis were meticulously cleaned and rinsed with distilled water.

2.5. Statistical Analysis

The data were described with mean, SE (standard error of the mean), frequency, and percentage with Microsoft Excel (Office Professional Plus 2020). The normal distribution of the data was tested by the Klomogorov-Smirnov test. It was found that the fiber data had a normal distribution ($p > 0.05$); therefore, the number of fibers was compared by the One-way ANOVA method, and the mean was compared by Scheffe's. Fragments and size were not normally distributed ($p < 0.01$), so the number of fragments and size were compared using the Kruskal-Wallis test.

3. Results and Discussion

3.1. Abundance of Microplastics

The microplastic abundance at different depths in sediment cores from stations KG01–KG04 is shown in Figure 2. Because the sediment at KG04 was much harder than at the other stations, we obtained a shorter core. Microplastics were detected in 84 sediment samples with a total of 1016 pieces from KG01–KG04. The abundance of microplastics in sediment cores ranged from 2.5–130.0 (Min–Max) particles/kg (dry weight) with an average abundance in cores KG01, KG02, KG03, and KG04 of 29.8 ± 17.5, 28.5 ± 15.9, 40.8 ± 21.3, and 56.5 ± 28.0 particles/kg dry weight, respectively. The highest concentrations of microplastics were observed at site KG04. Since the location of KG04 site is located near the mouth of the river, as the river flows, it could pick up sediment and microplastics from rivers and bring them to the mouth of the river. The river mouth is where much of the sediment and microplastics are deposited due to the slowing of the current, which reduces the energy to carry all the microplastics and particles [29]. Overall, the concentrations of microplastics in the core sediments collected at KG02, KG03, and KG04 sites show a decreasing trend from top to bottom with variations in the deep layers. This may be due to the accumulation of more microplastics that settled from seawater into the surface sediments in recent years. This vertical trend in the sediment has been reported in previous works [30,31]. However, KG01 showed a trend of increasing microplastics with depth. The region that this site is located in is abundant in mangrove forests. Reinold et al. reported that most microplastics (66%) were found in high-tide sediments, and only 11% were observed in low-tide sediments [32]. Therefore, it is likely that during high tide, mangrove roots might gather marine debris and microplastic, which would then be trapped or deposited inside the sediment of the mangroves or in the mangrove ecosystem [33]. This result shows the use of sediment cores to understand the history and trends of microplastic pollution. There was a temporal trend, showing that the abundance of microplastics in the sediment cores increased over time.

3.2. Physical Characteristics of Microplastics: Shape, Size, and Color

The results of the shape, size, and color classification of microplastics are shown in Figures 3–5. An example of microplastic shapes collected from Kuala Gula Mangrove, Malaysia, is shown in Figure 3.

3.2.1. Shape

Different shapes of microplastics were observed in the four stations of sediment cores at Kuala Gula Mangrove, Malaysia (Figure 3). Fibers were the most prominent microplastics, with an average of 88.0%, followed by fragments with an average of ~10.1% and others with an average of 1.9%. Similar results for shapes of microplastics in sediment cores, in which fibers were the main types, were observed in Qingdao Beach [34] and Hangzhou Bay, China [35]. Microplastic fibers are formed in the textile industry as staple fibers or filaments are released during washing and laundry [36]. Belzagui et al. [37] reported that about 0.28 million tons/year of microplastic fibers was released into the aquatic environment via washing and removal during wastewater treatment. The elongated form of the fibers and the very large surface area to volume ratio increases the chance of adhering to inorganic sediment particles. Additionally, fibers towards the flow's base are more likely to be trapped and buried by depositing sediment [38]. It is possible that the high concentration of fibers at the Kuala Gula Mangrove may be the result of microplastic particles being carried from municipal and fishing villages with a population of 7200 people outside the mangrove area.

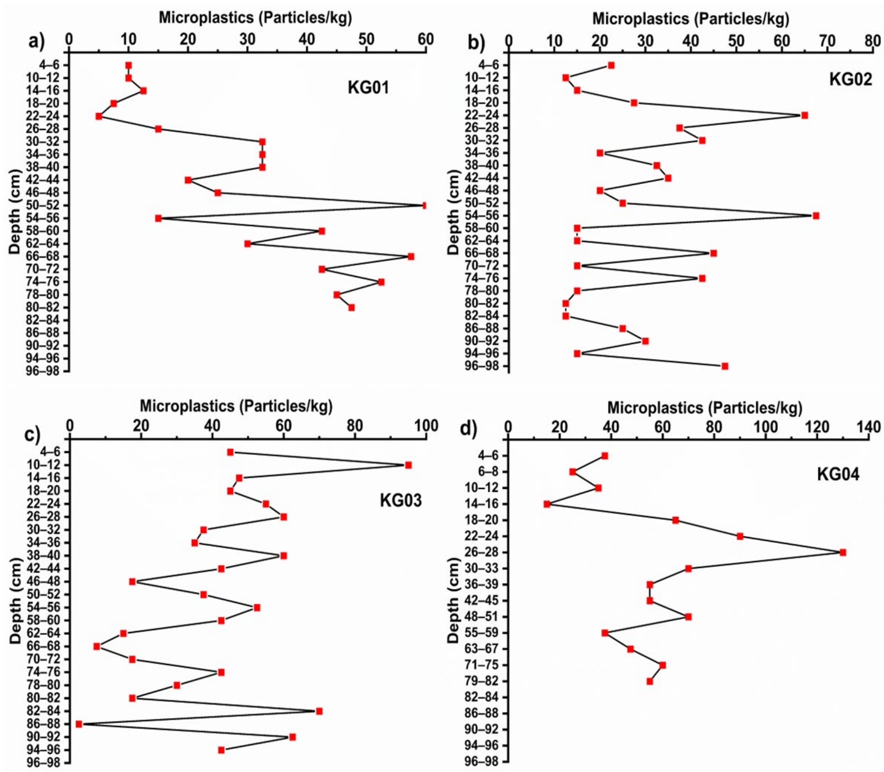

Figure 2. Abundance of microplastics at different depths in sediment cores: (**a**) KG01; (**b**) KG02; (**c**) KG03; and (**d**) KG04 from Kuala Gula Mangrove, Malaysia.

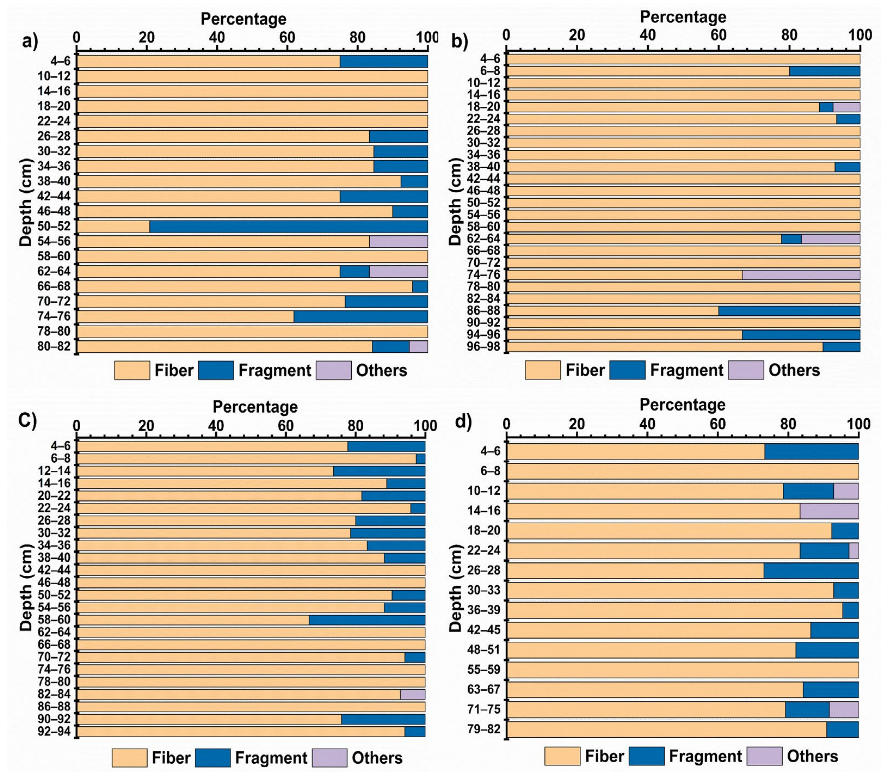

Figure 3. Percent of microplastic occurrence based on shape at stations (**a**) KG01; (**b**) KG02; (**c**) KG03; and (**d**) KG04 from Kuala Gula Mangrove, Malaysia.

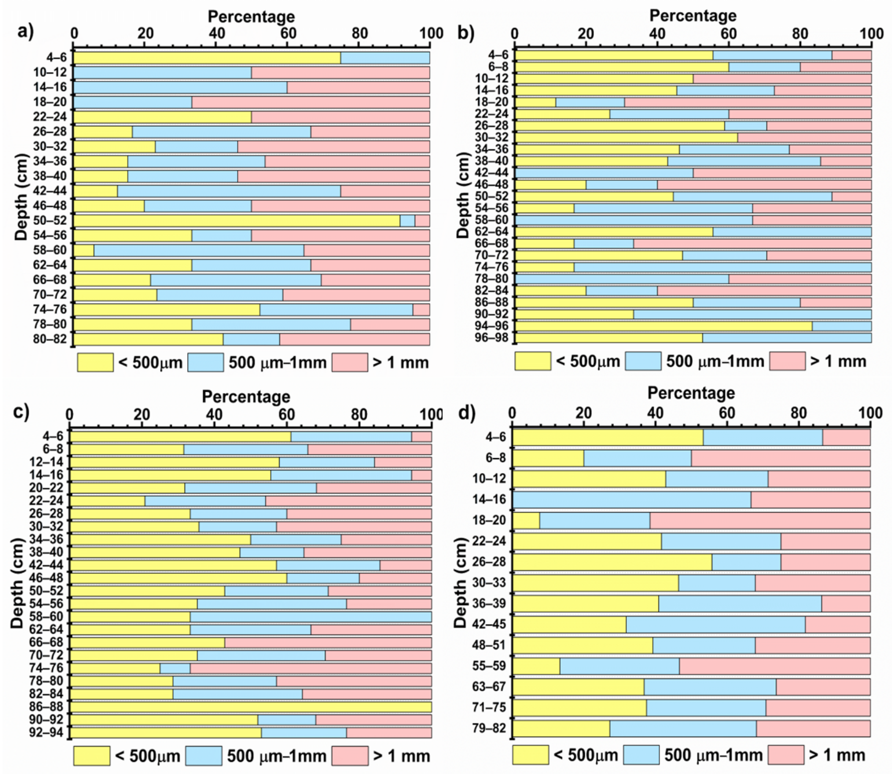

Figure 4. Percent of microplastic occurrence based on size at stations (**a**) KG01; (**b**) KG02; (**c**) KG03; and (**d**) KG04 from Kuala Gula Mangrove, Malaysia.

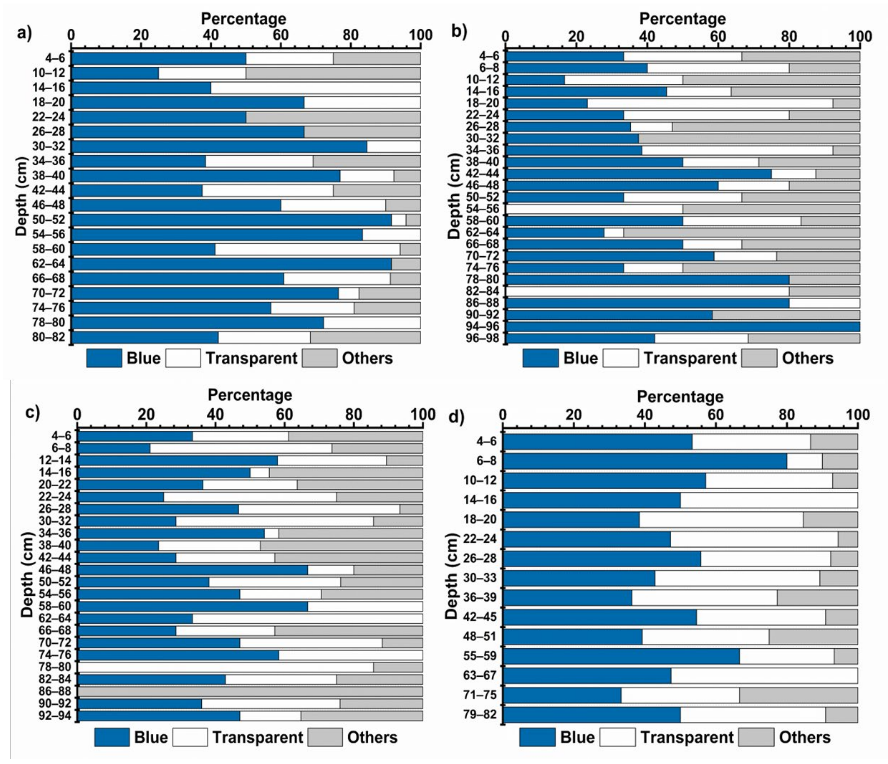

Figure 5. Percent of microplastic occurrence based on color at stations (**a**) KG01; (**b**) KG02; (**c**) KG03; and (**d**) KG04 in Kuala Gula Mangrove, Malaysia.

3.2.2. Size

Figure 4 shows the different size distributions at all stations. Microplastics were classified into three types in the size range of <500 µm, 500 µm–1 mm, and >1 mm on the basis of their size. At sites KG02 and KG03, <500 µm microplastics had the highest percentage with 37% and 44%, respectively. Meanwhile, the highest percentage of microplastics in stations KG01 and KG04 were larger (>1 mm) with 37% and 35% (500 µm–1 mm), respectively. Previous works have shown that microplastics smaller than 100 µm are predominant [39] and tend to aggregate with natural colloids, which leads to their increased precipitation [40]. In addition, microplastics sized >500 µm have been observed in mangroves. It is possible that the roots of mangroves can serve to trap even larger moving objects. However, small microplastics were also found to accumulate in mangroves in many areas, such as Singapore's coast [41] and Beijing, China [42]. This may be due to the differences between the estuarine and fringe mangroves. The small size of microplastics might pose potential threats to the biota due to their strong adsorption of persistent organic pollutants (POPs) and easy transportation to the tissues.

3.2.3. Color

Figure 5 shows the color distribution at all stations. At site KG01, 61% of microplastics found were blue in color, with transparent (Figure 6) and other colors contributing to 23% and 16.4%, respectively. For KG02, the main color of microplastics was blue (44%), and the proportions of transparent and others were 26.4% and 29.6%, respectively. Blue was predominant (38%), followed by transparent (34.2%) and other (27.5%) at site KG03. KG04 showed the same trend, with blue microplastics representing 50.1%, followed by transparent (38.1%) and others (11.7%). The results indicate that blue is the predominant color of microplastics found in the Kuala Gula Mangrove, which corresponds with other studies [43]. The variation in different colors in the study area might be due to various microplastic sources. At the same time, blue and transparent plastic might be widely used in this area. It is possible that the color of microplastics might originate from packaging, fishing, and textile-related activities in surrounding residential areas. It was deposited in the sediment, creating large amounts of blue and transparent debris through cracking [44]. Ory et al. [45] showed that marine fauna can confuse their common prey with microplastic colors. They reported that plankton fish preferred blue-colored fragments because it is similar to their prey in the natural environment [45]. Thus, the color of microplastic might be an important factor that affects the transportation of pollutants to higher chain levels.

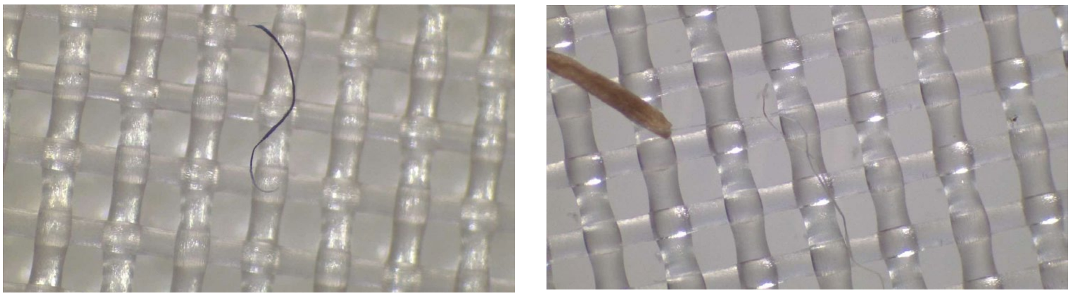

Figure 6. Examples of microplastic color shapes collected from Kuala Gula Mangrove, Malaysia (**left**: blue color; **right**: transparent).

3.2.4. Type of Microplastic Polymers

The collected microplastics were further studied by FT-IR in Figure 7. Four main types of polymer were found, with three types classified as microplastics (synthetic polymer) which were found in the sediment cores in this study, namely rayon, polyethylene terephthalate (PET), and azlon, while one type of natural polymer found was cotton. The presence of cotton and rayon fibers in this study indicates that these fibers originate from the degradation of natural and synthetic woven textiles [46]. Rayon was the most widely distributed and abundant microplastic in the studied sediment core. This can be seen by the fiber, which shows a broad band at 3435.0 (O-H str), 2894.3 (C-H str), 1064.0 (C-O-C str), and 897.1 cm^{-1} (C-C str) vibrations [47]. Rayon is a man-made fiber used in personal hygiene products and textiles. Many previous works report that rayon fibers are a major source of microplastics in the deep sea [48] and have been found to contaminate fish gastrointestinal tract [49]. PET may be released from food packaging and beverages, especially carbonated soft drinks, juices, and water and also woven belts, filter cloth, and others [50]. These results indicate that the presence of rayon, cotton, azlon, and polyethylene terephthalate could be related to municipal waste outflows since all these polymers are generally used in the textile industry and therefore are released due to washing clothes.

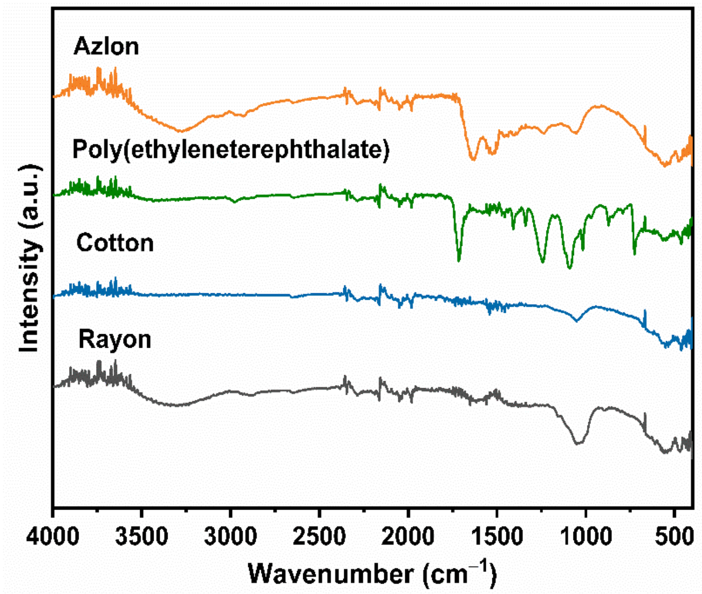

Figure 7. FT-IR of microplastics found in Kuala Gula Mangrove, Malaysia.

3.2.5. Statistical Analysis

Table 2 offers descriptive information about the fibers, fragments in the sediment core, and other types of microplastics that were examined. The number of microplastics by sampling site was significantly different ($p < 0.01$), with station KG04 having the highest fiber content. The highest abundance by the number of fibers was found at station KG04 (19.20), and fewer fibers were found at the KG01 (9.45) and KG02 (10.60) sites. In addition, the number of microplastics sized (<500, 500–1 mm, and >1 mm) by sampling site were significantly different ($p < 0.01$). Overall, microplastics of every size class were found to have the highest content at station KG04. This is attributed to the location of KG04 sites which are located near the mouth of the river, where a large amount of sediment and microplastics are deposited. Chi-square values were used to analyze color classification according to sampling points, and it was discovered that there was no statistically significant difference ($p > 0.05$). Simple linear regression was carried out to test the relationship between microplastic particles per kilogram and the depth of all sediment cores. Microplastics tend to accumulate in deeper depth at KG01 ($p < 0.01$), whereas other stations showed no significant difference ($p > 0.05$). Overall, at the surface, it can be seen that the top layer (0–20 cm) in the river stations (KG01, KG02) had fewer microplastics than the river mouth (KG03, KG04), and the accumulation was highest at station KG03, although in the 20–40 cm and 40–60 cm layers, KG04 had the most microplastic (Figure 8). The microplastic abundance reported in this study is in the same range as reported in the mangrove area at the North Coast of the Persian Gulf [51] and Songkhla Lagoon, Thailand [22].

Table 2. Descriptive information relating to the number (particles) of fibers, fragments, and others with various sizes of microplastics in the sediment cores.

Station	Values	Fibers	Fragment	Others	<500 µm	500 µm–1 mm	>1 mm
KG01	Mean	9.45	2.25	0.20	3.90	4.15	3.85
	S.E.	1.28	0.98	0.12	1.14	0.71	0.57
	Median	9.00	1.00	0.00	2.00	3.00	3.50
KG02	Mean	10.60	0.52	0.28	4.40	3.88	3.12
	S.E.	1.22	0.19	0.16	0.69	0.59	0.72
	Median	9.00	0.00	0.00	4.00	3.00	3.00
KG03	Mean	14.46	1.79	0.08	6.75	4.71	4.88
	S.E.	1.604	0.37	0.08	0.76	0.65	0.71
	Median	15.00	1.50	0.00	6.50	4.00	4.50
KG04	Mean	19.20	3.07	0.33	8.40	7.33	6.87
	S.E.	2.19	0.89	0.16	1.83	0.72	1.03
	Median	19.00	2.00	0.00	7.00	8.00	7.00
	Mean	12.96	1.75	0.21	5.67	4.80	4.46
	S.E.	0.84	0.32	0.07	0.54	0.35	0.39
	Median	12.00	1.00	0.00	5.00	4.00	4.00

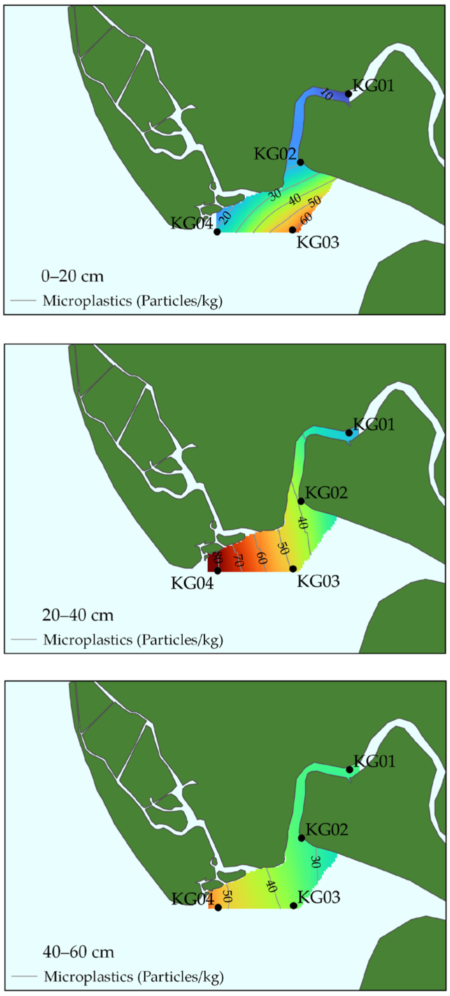

Figure 8. Abundance of microplastics at different depths in sediment cores from Kuala Gula Mangrove, Malaysia.

4. Conclusions

The present study is the first to report the microplastic content in the core sediment of Kuala Gula Mangrove, Malaysia. Our data indicate that high amounts of microplastics were collected and deposited near the mouth of the river, especially at the KG04 site. The number of microplastics at KG02, KG03, and KG04 decreased with increasing depth, showing increased production and use of microplastics over time. Meanwhile, KG01 showed a trend of increasing microplastics with depth. The majority of the microplastics were fibers and fragments which could be released during washing and laundry by the community. Most microplastics were sized less than 500 µm, and the predominant color was blue. FTIR spectroscopy analysis revealed the existence of rayon, cotton, azlon, and polyethylene terephthalate which indicate that textile materials and food packaging were possible sources of microplastics. Thus, appropriate solid waste management and investigations on microplastic contamination are required to prevent microplastic pollution in the environment, especially in mangrove wetlands.

Author Contributions: Conceptualization, C.A.R.M., S.P. and P.S.L.; Data curation, T.N., T.K. and C.W.L.; Formal analysis, A.N.S., T.K., T.S. and S.K.; Investigation, C.A.R.M., A.N.S. and C.W.B.; Methodology, S.P., T.N. and P.N.; Writing—original draft, C.A.R.M., S.P. and P.N.; Writing—review & editing, S.P., P.S.L., T.P.Q.L., C.O., X.L., G.Z.A. and J.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Asia-Pacific Network for Global Change Research (APN): grant number CRRP2020-06MY-Loh.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Plastics Europe. *Plastics—The Facts 2020: An Analysis of European Plastics Production, Demand and Recovery for 2020*; Plastics Europe Market Research Group [PEMRG]: Brussels, Belgium, 2021.
2. Santodomingo, N.; Perry, C.; Waheed, Z.; Syed Hussein, M.A.B.; Rosedy, A.; Johnson, K.G. Marine litter pollution on coral reefs of Darvel Bay (East Sabah, Malaysia). *Mar. Pollut. Bull.* **2021**, *173*, 112998. [CrossRef] [PubMed]
3. Tan, E.; Jaafar, N.F.; Aileen Tan, S.H.; Mohd Zanuri, N.B. A review of plastic and microplastic pollution towards the Malaysian marine environment. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1013*, 012012. [CrossRef]
4. Picó, Y.; Barceló, D. Analysis and Prevention of Microplastics Pollution in Water: Current Perspectives and Future Directions. *ACS Omega* **2019**, *4*, 6709–6719. [CrossRef] [PubMed]
5. Pradit, S.; Nitiratsuwan, T.; Towatana, P.; Jualaong, S.; Sornplang, K.; Noppradit, P.; Jirajarus, M.; Darakai, Y.; Weerawong, C. Marine debris accumulation on the beach in libong, a small island in andaman sea, thailand. *Appl. Ecol. Environ. Res.* **2020**, *18*, 5461–5474. [CrossRef]
6. Han, X.-L.; Jiang, N.-J.; Hata, T.; Choi, J.; Du, Y.-J.; Wang, Y.-J. Deep learning based approach for automated characterization of large marine microplastic particles. *Mar. Environ. Res.* **2023**, *183*, 105829. [CrossRef]
7. Patterson, J.; Jeyasanta, K.I.; Sathish, N.; Edward, J.K.P.; Booth, A.M. Microplastic and heavy metal distributions in an Indian coral reef ecosystem. *Sci. Total Environ.* **2020**, *744*, 140706. [CrossRef]
8. Botterell, Z.L.R.; Bergmann, M.; Hildebrandt, N.; Krumpen, T.; Steinke, M.; Thompson, R.C.; Lindeque, P.K. Microplastic ingestion in zooplankton from the Fram Strait in the Arctic. *Sci. Total Environ.* **2022**, *831*, 154886. [CrossRef]
9. Azad, S.M.O.; Towatana, P.; Pradit, S.; Patricia, B.G.; Hue, H.T. Ingestion of microplastics by some commercial fishes in the lower Gulf of Thailand: A preliminary approach to ocean conservation. *Int. J. Agric. Technol.* **2018**, *14*, 1017–1032.
10. Li, Q.; Ma, C.; Zhang, Q.; Shi, H. Microplastics in shellfish and implications for food safety. *Curr. Opin. Food Sci.* **2021**, *40*, 192–197. [CrossRef]
11. Hossain, M.S.; Rahman, M.S.; Uddin, M.N.; Sharifuzzaman, S.M.; Chowdhury, S.R.; Sarker, S.; Nawaz Chowdhury, M.S. Microplastic contamination in Penaeid shrimp from the Northern Bay of Bengal. *Chemosphere* **2020**, *238*, 124688. [CrossRef]
12. Liu, S.; Shi, J.; Wang, J.; Dai, Y.; Li, H.; Li, J.; Liu, X.; Chen, X.; Wang, Z.; Zhang, P. Interactions Between Microplastics and Heavy Metals in Aquatic Environments: A Review. *Front. Microbiol.* **2021**, *12*, 652520. [CrossRef]
13. Frias, J.P.G.L.; Sobral, P.; Ferreira, A.M. Organic pollutants in microplastics from two beaches of the Portuguese coast. *Mar. Pollut. Bull.* **2010**, *60*, 1988–1992. [CrossRef]

14. Kwon, J.-H.; Chang, S.; Hong, S.H.; Shim, W.J. Microplastics as a vector of hydrophobic contaminants: Importance of hydrophobic additives. *Integr. Environ. Assess. Manag.* **2017**, *13*, 494–499. [CrossRef]
15. Mamun, A.A.; Prasetya, T.A.E.; Dewi, I.R.; Ahmad, M. Microplastics in human food chains: Food becoming a threat to health safety. *Sci. Total Environ.* **2023**, *858*, 159834. [CrossRef] [PubMed]
16. Gijsman, R.; Horstman, E.M.; van der Wal, D.; Friess, D.A.; Swales, A.; Wijnberg, K.M. Nature-Based Engineering: A Review on Reducing Coastal Flood Risk with Mangroves. *Front. Mar. Sci.* **2021**, *8*, 702412. [CrossRef]
17. Powell, E.J.; Tyrrell, M.C.; Milliken, A.; Tirpak, J.M.; Staudinger, M.D. A review of coastal management approaches to support the integration of ecological and human community planning for climate change. *J. Coast. Conserv.* **2018**, *23*, 1–18. [CrossRef]
18. Martin, C.; Almahasheer, H.; Duarte, C.M. Mangrove forests as traps for marine litter. *Environ. Pollut.* **2019**, *247*, 499–508. [CrossRef]
19. Ibrahim, N.A.; Khairul Anuar, M.H.H.; Mazlan, M.A.Y.U.; Ahmad Nahar, A.M.; Syed Alyan, S.N.N.; Zakaria, N.A.; Hashim, M.A.; Ahmad Kamil, K. Abundance, Uptake, Presence and Biodegradation of Microplastics in Malaysian Context: A Systematic Literature Review. *J. Sustain. Sci. Manag.* **2022**, *17*, 221–239. [CrossRef]
20. Barasarathi, J.; Agamuthu, P.; Emenike, C.U.; Fauziah, S.H. Microplastic abundance in selected mangrove forest in Malaysia. In Proceedings of the ASEAN Conference on Science and Technology, Bogor, Indonesia, 18–27 August 2014.
21. Hamid, F.S.; Jia, W.; Zakaria, R.M. Microplastics Abundance and Uptake by Meretrix lyrata (Hard Clam) in Mangrove Forest. *J. Eng. Technol. Sci.* **2020**, *52*, 436–448. [CrossRef]
22. Pradit, S.; Noppradit, P.; Loh, P.-S.; Nitiratsuwan, T.; Le, T.P.Q.; Oeurng, C.; Mohamed, C.A.R.; Lee, C.W.; Lu, X.; Anshari, G.Z.; et al. The Occurrence of Microplastics in Sediment Cores from Two Mangrove Areas in Southern Thailand. *J. Mar. Sci. Eng.* **2022**, *10*, 418. [CrossRef]
23. Azam, S.N.; Unjah, T. Innovative Management of Natural Resources: Case Study of Mangrove Area in Kuala Gula, Perak. *Plan. Malays. J.* **2017**, *15*, 45–56. [CrossRef]
24. Ismail, A.; Rahman, F. Current Status of the Milky Stork Re-introduction Programme in Malaysia and Its Challenges. *Trop. Life Sci. Res.* **2016**, *27*, 13–24. [CrossRef] [PubMed]
25. Chinfak, N.; Sompongchaiyakul, P.; Charoenpong, C.; Shi, S.; Yeemin, T.; Zhang, J. Abundance, composition, and fate of microplastics in water, sediment, and shellfish in the Tapi-Phumduang River system and Bandon Bay, Thailand. *Sci. Total Environ.* **2021**, *781*, 146700. [CrossRef]
26. Wang, S.; Chen, H.; Zhou, X.; Tian, Y.; Lin, C.; Wang, W.; Zhou, K.; Zhang, Y.; Lin, H. Microplastic abundance, distribution and composition in the mid-west Pacific Ocean. *Environ. Pollut.* **2020**, *264*, 114125. [CrossRef]
27. Jahan, S.; Strezov, V.; Weldekidan, H.; Kumar, R.; Kan, T.; Sarkodie, S.A.; He, J.; Dastjerdi, B.; Wilson, S.P. Interrelationship of microplastic pollution in sediments and oysters in a seaport environment of the eastern coast of Australia. *Sci. Total Environ.* **2019**, *695*, 133924. [CrossRef]
28. Jiwarungrueangkul, T.; Phaksopa, J.; Sompongchaiyakul, P.; Tipmanee, D. Seasonal microplastic variations in estuarine sediments from urban canal on the west coast of Thailand: A case study in Phuket province. *Mar. Pollut. Bull.* **2021**, *168*, 112452. [CrossRef] [PubMed]
29. Gardel, A.; Anthony, E.J.; Santos, V.F.; Huybrechts, N.; Lesourd, S.; Sottolichio, A.; Maury, T. A remote sensing-based classification approach for river mouths of the Amazon-influenced Guianas coast. *Reg. Environ. Chang.* **2022**, *22*, 65. [CrossRef]
30. Yu, L.; Li, R.; Chai, M.; Li, B. Vertical distribution, accumulation, and characteristics of microplastics in mangrove sediment in China. *Sci. Total Environ.* **2022**, *856*, 159256. [CrossRef] [PubMed]
31. Dong, M.; Luo, Z.; Jiang, Q.; Xing, X.; Zhang, Q.; Sun, Y. The rapid increases in microplastics in urban lake sediments. *Sci. Rep.* **2020**, *10*, 848. [CrossRef]
32. Reinold, S.; Herrera, A.; Stile, N.; Saliu, F.; Hernández-González, C.; Martinez, I.; Ortega, Z.; Marrero, M.D.; Lasagni, M.; Gómez, M. An annual study on plastic accumulation in surface water and sediment cores from the coastline of Tenerife (Canary Island, Spain). *Mar. Pollut. Bull.* **2021**, *173*, 113072. [CrossRef]
33. Zandhi, R.; Yuliadi, L.P.S.; Ismail, M.R.; Yuniarti, M.S. Conditions for Sediment Coating Microplastic in Mangrove Ecosystems in Kupang and Rote, East Nusa Tenggara, Indonesia. *World News Nat. Sci.* **2019**, *27*, 50–58.
34. Pervez, R.; Wang, Y. Microplastic distribution within core sediments of beach and its responses to anthropogenic activities. *Mar. Pollut. Bull.* **2022**, *174*, 113256. [CrossRef]
35. Li, J.; Huang, W.; Xu, Y.; Jin, A.; Zhang, D.; Zhang, C. Microplastics in sediment cores as indicators of temporal trends in microplastic pollution in Andong salt marsh, Hangzhou Bay, China. *Reg. Stud. Mar. Sci.* **2020**, *35*, 101149. [CrossRef]
36. Yang, T.; Gao, M.; Nowack, B. Formation of microplastic fibers and fibrils during abrasion of a representative set of 12 polyester textiles. *Sci. Total Environ.* **2023**, *862*, 160758. [CrossRef]
37. Belzagui, F.; Gutiérrez-Bouzán, C.; Álvarez-Sánchez, A.; Vilaseca, M. Textile microfibers reaching aquatic environments: A new estimation approach. *Environ. Pollut.* **2020**, *265*, 114889. [CrossRef]
38. Pohl, F.; Eggenhuisen, J.T.; Kane, I.A.; Clare, M.A. Transport and Burial of Microplastics in Deep-Marine Sediments by Turbidity Currents. *Environ. Sci. Technol.* **2020**, *54*, 4180–4189. [CrossRef]
39. Wu, P.; Tang, Y.; Dang, M.; Wang, S.; Jin, H.; Liu, Y.; Jing, H.; Zheng, C.; Yi, S.; Cai, Z. Spatial-temporal distribution of microplastics in surface water and sediments of Maozhou River within Guangdong-Hong Kong-Macao Greater Bay Area. *Sci. Total Environ.* **2020**, *717*, 135187. [CrossRef] [PubMed]

40. Besseling, E.; Quik, J.T.K.; Sun, M.; Koelmans, A.A. Fate of nano- and microplastic in freshwater systems: A modeling study. *Environ. Pollut.* **2017**, *220*, 540–548. [CrossRef]
41. Mohamed Nor, N.H.; Obbard, J.P. Microplastics in Singapore's coastal mangrove ecosystems. *Mar. Pollut. Bull.* **2014**, *79*, 278–283. [CrossRef] [PubMed]
42. Zhang, M.; Liu, L.; Xu, D.; Zhang, B.; Li, J.; Gao, B. Small-sized microplastics (<500 µm) in roadside soils of Beijing, China: Accumulation, stability, and human exposure risk. *Environ. Pollut.* **2022**, *304*, 119121. [CrossRef] [PubMed]
43. Chen, X.; Chen, X.; Liu, Q.; Zhao, Q.; Xiong, X.; Wu, C. Used disposable face masks are significant sources of microplastics to environment. *Environ. Pollut.* **2021**, *285*, 117485. [CrossRef] [PubMed]
44. Kelly, M.R.; Lant, N.J.; Kurr, M.; Burgess, J.G. Importance of Water-Volume on the Release of Microplastic Fibers from Laundry. *Environ. Sci. Technol.* **2019**, *53*, 11735–11744. [CrossRef]
45. Ory, N.C.; Sobral, P.; Ferreira, J.L.; Thiel, M. Amberstripe scad Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. *Sci. Total Environ.* **2017**, *586*, 430–437. [CrossRef]
46. Periyasamy, A.P.; Tehrani-Bagha, A. A review on microplastic emission from textile materials and its reduction techniques. *Polym. Degrad. Stab.* **2022**, *199*, 109901. [CrossRef]
47. Kaur, I.; Sharma, N.; Kumari, V. Modification of fiber properties through grafting of acrylonitrile to rayon by chemical and radiation methods. *J. Adv. Res.* **2013**, *4*, 547–557. [CrossRef] [PubMed]
48. Woodall, L.C.; Sanchez-Vidal, A.; Canals, M.; Paterson, G.L.J.; Coppock, R.; Sleight, V.; Calafat, A.; Rogers, A.D.; Narayanaswamy, B.E.; Thompson, R.C. The deep sea is a major sink for microplastic debris. *R. Soc. Open Sci.* **2014**, *1*, 140317. [CrossRef] [PubMed]
49. Lusher, A.L.; McHugh, M.; Thompson, R.C. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Mar. Pollut. Bull.* **2013**, *67*, 94–99. [CrossRef]
50. Tsironi, T.N.; Chatzidakis, S.M.; Stoforos, N.G. The future of polyethylene terephthalate bottles: Challenges and sustainability. *Packag. Technol. Sci.* **2022**, *35*, 317–325. [CrossRef]
51. Naji, A.; Nuri, M.; Amiri, P.; Niyogi, S. Small microplastic particles (S-MPPs) in sediments of mangrove ecosystem on the northern coast of the Persian Gulf. *Mar. Pollut. Bull.* **2019**, *146*, 305–311. [CrossRef]