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Abundance and Characteristics of Microplastics in Coral Reefs at Penimbangan Waters

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Abstract. Coral reefs are a vital component of marine ecosystems, playing a crucial role in providing and protecting marine biodiversity. However, recent studies have found the presence of microplastics in corals, which have been proven to threaten their health. This study aims to identify the abundance and characteristics of microplastics in coral reefs in the waters of Penimbangan Beach. A total of 12 coral samples were collected from two stations selected based on the presence of coral reefs in the area and then analyzed in the laboratory. Microplastic separation was carried out using hydrochloric acid (HCl) and sodium chloride (NaCl) solutions. Subsequently, an analysis was conducted to determine the abundance and identify the shape, size, and color of the microplastics. The research results showed that the highest microplastic abundance was found at Station 1 (3.5 particles/gram), while the lowest was at Station 2 (1.6 particles/gram). The characteristics of microplastics found were predominantly fibers (94.6%), followed by fragments and granules. The most commonly found microplastic size was 0.001–1 mm (53%), followed by 1–5 mm. The dominant microplastic color was black, followed by blue, red, transparent, and brown.

Keywords: Coral; Identification; Microplastics; Penimbangan Beach.

I. INTRODUCTION

Microplastic pollution is one of the most recent threats to marine ecosystems. According to the International Organization for Standardization (ISO), microplastics are plastic particles measuring between 0.001 mm and 5 mm, which can be classified into two types: primary microplastics, which are directly manufactured in factories [1], and secondary microplastics, which result from the degradation of larger plastic products and are estimated to originate primarily from plastic waste [2]. Approximately 60% to 87% of waste in the global environment consists of plastics, and each year, around 0.5% of global plastic waste is estimated to enter the marine environment. The entry of plastic waste into the ocean is mainly caused by improper waste disposal and inadequate land-based waste management [3]. Once in the sea, plastics undergo physical, chemical, and biological degradation processes, resulting in the formation of microplastics [4].

Once microplastics enter the ocean, these particles may float on the surface or sink to the seabed [5]. Several studies have shown that various marine organisms have the potential to ingest and accumulate microplastics [6], [7]. Based on these findings, scientists predict that one of the most diverse and vital marine ecosystems—coral reefs—may also be susceptible to microplastic ingestion and accumulation [8].

Coral reefs are limestone structures formed by colonies of coral polyps [9]. These ecosystems play a crucial role as habitats, shelters, spawning grounds, and food sources for a wide range of marine organisms [10]. However, coral reefs are highly vulnerable to environmental stressors such as anthropogenic activities, ocean acidification, and global warming [11], [12]. Among these stressors, microplastics have been identified as a significant threat to coral health. Several in situ experiments have shown that corals tend to ingest microplastics due to their non-selective feeding behavior and the resemblance in size between microplastics and their natural food sources [13]. Moreover, microplastics can adhere to coral surfaces through adhesion processes, aided by mucus secreted by corals in response to foreign particles [14], [15].

Microplastic accumulation on coral tissues can lead to physiological disruptions, impaired immune functions, increased disease susceptibility, coral bleaching, and reduced growth rates [16],[17],[18]. Additionally, microplastics can act as vectors for pathogens through biofilm formation on their surfaces, thereby increasing the risk of coral infections [19].

One of the marine areas with coral reef ecosystems is Penimbangan Waters, located in Singaraja, Buleleng, Bali. The coral reef area in this region spans approximately 26 hectares and has been designated as a conservation zone. However, despite its protected status, the area continues to face issues with waste pollution. According to a report [20], Penimbangan Waters remains threatened by waste originating from nearby settlements and river outflows that discharge into the area, where rivers can serve as major pathways for the spread of microplastics into the marine environment [21]. Furthermore, the fishing activities around this zone also contribute to solid waste pollution. As a tourist destination, the area also faces the risk of increased plastic pollution [22], [23]. The presence of such waste may serve as a significant source of microplastic pollution, posing a threat to the coral reef ecosystem as previously described.

Previous studies have confirmed the presence of microplastics in seawater and seafloor sediments in Bali [24], [25]. However, to date, no specific research has focused on the presence of microplastics within coral tissues in Penimbangan Waters. Therefore, this study aims to investigate the presence of microplastics in corals from this location.

II. METHODS

A. Research Time and Location

The research was conducted in the waters of Pantai Penimbangan, Buleleng, Bali, on September 7, 2024. Coral samples were collected from two stations selected using the purposive sampling method, ensuring they represented the coral reef ecosystem in the waters of Pantai Penimbangan. Each station consisted of six sampling points, also chosen using the purposive sampling method based on the presence of coral reef ecosystems in the area. The research location is shown in Figure 1.

B. Research Method

A survey was conducted at Pantai Penimbangan to determine the location of coral reefs, with mapping assistance from POKWAMAS. Based on the survey results, two research stations were established, each containing six live coral samples of the Acropora species for microplastic analysis. Acropora corals were chosen due to their ease of sampling and environmentally friendly characteristics, as they have a fast growth rate, making them more resilient to sampling impacts. Coral samples were collected from a depth of 5–7 meters using coral cutting tools, with each sample measuring 4–7 cm. The samples were placed in glass bottles filled with seawater and stored in a cool box for temporary preservation for three days before being transported to the laboratory for further storage and analysis.

The coral samples were transported to the Fisheries Laboratory at the Faculty of Marine and Fisheries, Udayana University. Before analysis, the corals were weighed to determine their wet weight. To separate microplastics from the corals, the method by Allen et al. (2017) was applied. First, the coral colonies were placed in a beaker and soaked in a saturated sodium chloride (NaCl) solution, allowing the plastic particles to float. The saturated NaCl solution was prepared by mixing 35.88 grams of sodium chloride with 100 ml of distilled water using a magnetic stirrer at 20°C. After 30 minutes, the solution was filtered using a 0.1 mm sieve, and the filtrate was transferred into a 150 ml beaker. Then, 20 ml of 30% hydrogen peroxide (H_2O_2) was added to eliminate other organic matter, followed by heating in an oven for 24 hours.

After the NaCl treatment, the coral skeleton was transferred to a new beaker and dissolved in 37% hydrochloric acid (HCl) for 30 minutes, or until it was fully dissolved. Another NaCl solution was then added to float microplastics, and the mixture was filtered again using the same 0.1 mm sieve. The filtrate was transferred into a second 150 mL beaker. Next, 30% hydrogen peroxide was added to the beaker, and the sample was placed in an oven for 24 hours. The final solution from both beakers was filtered using a vacuum filter with a 0.45 µm Whatman filter paper. The filter paper was then placed in a petri dish and dried in a laboratory oven at 50°C for 3 hours. After this process, the samples were ready for identification.

C. Data Analysis

The filter paper was observed under a microscope with the aid of Opti Lab software to capture images of microplastics and measure their sizes based on the microplastic size criteria of 0.1–1 mm and 1–5 mm. The identification of microplastics followed the criteria established by Hidalgo-Ruz *et al.* (2012) and the guidelines from the Marine & Environmental Research Institute (MERI), using the following key identification characteristics:

a) Microplastics do not exhibit organic or cellular structures.
b) Their appearance is always inconsistent with the surrounding matrix or contamination sources.
c) Fibers must have uniform thickness throughout the whole length
d) Microplastic particles must display a homogeneous color.

A hot needle test (Kovač Viršek *et al.,* 2016) was performed to confirm the presence of microplastics, as they degrade when exposed to high temperatures. After confirmation, microplastics were measured using the Image Raster application. The sizes of microplastics were then categorized based on the method by Hansani (2023) into two groups: 0.001 mm–1 mm and 1 mm–5 mm. Furthermore, color identification is done visually, while shapes can be categorized into fiber, fragment, foam, film, and granule.

After identification, a quantitative analysis was conducted to determine the abundance of microplastics in corals. The abundance of microplastics was calculated using the formula from Hansani *et al.* (2023) and Hall *et al.* (2015):

$$c = \frac{n}{m}$$

Noted: C is abundance (particle/gram); n is total particle; m is wet weight of coral (gram).

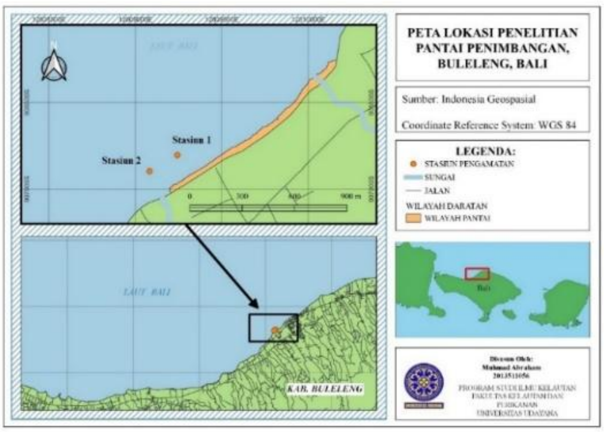

Figure 1. Research Located

III. RESULTS AND DISCUSSION

A. *Microplastic Abundance*

At Station 1, a total of 203 microplastic particles were found with a wet coral weight of 98 grams, whereas Station 2 contained 131 particles with a wet coral weight of 78 grams. The average microplastic abundance at both stations in Pantai Penimbangan was recorded at 1.95 ± 0.60 particles/gram. The highest microplastic abundance was found at Station 1, with an average of 2.15 ± 0.74 particles/gram, while Station 2 had an average of 1.76 ± 0.60 particles/gram, as shown in Figure 2.

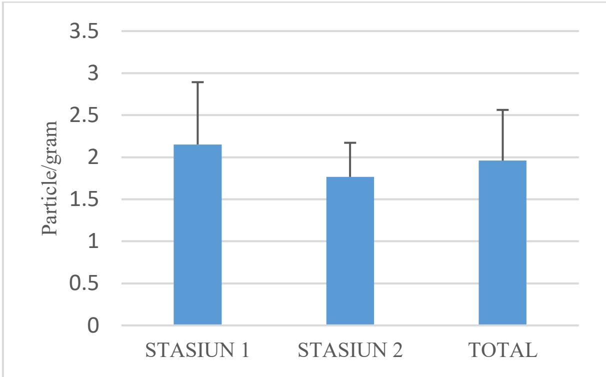

Figure 2. Graph of Average Coral Microplastic Abundance at Penimbangan Waters Station

B. *Microplastic Characteristics*

Microplastics can be categorized into five shapes: fiber, fragment, granule, film, and foam (Archina, 2022). However, in the coral reefs of Penimbangan Waters, only three shapes were found: fiber, fragment, and granule, as shown in Figure 3.

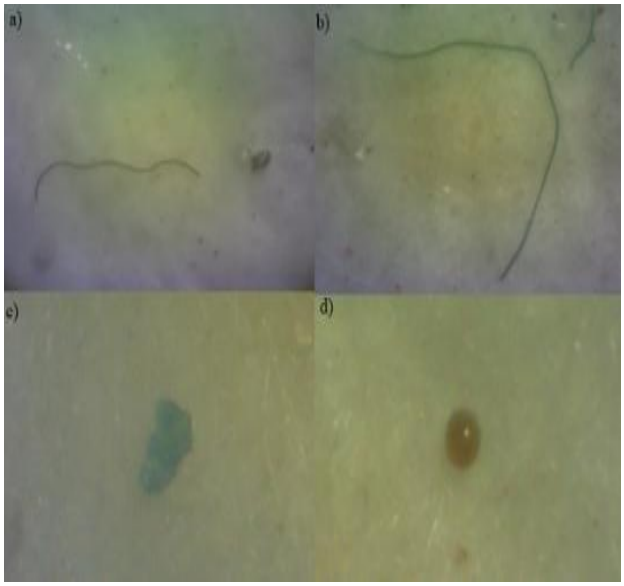

Figure 3. Coral Microplastic in Penimbangan Water a) *fiber black;* (b) *fiber blue*; (c) *fragment blue*; (d) *granula*

Microplastic fibers were the most dominant form, totaling 316 particles (94.6%). In Station 1, 194 fiber microplastics were found, while Station 2 contained 121 particles. Fragment microplastics were identified in 17 particles (5.1%), with seven particles in Station 1 and 10 in Station 2. The least common type was granules, with only one particle found in Station 1 and none in Station 2. The pie chart illustrating the microplastic forms in corals from Penimbangan Waters is shown in Figure 4.

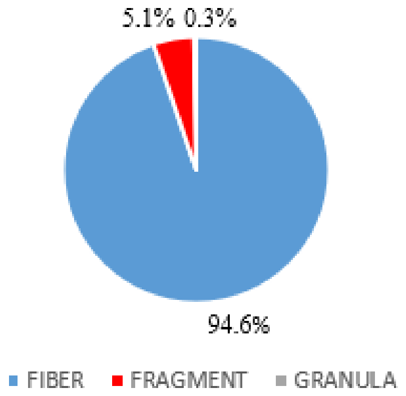

Figure 4. Pie Chart of the Percentage of Microplastic Shapes in Reef Penimbangan Water

In this study, the microplastic sizes in corals at Penimbangan waters were categorized into two groups: 0.001–1 mm and 1–5 mm. The smaller size category (0.001–1 mm) was dominant, accounting for 53% of the total microplastics. In Station 1, 98 particles were found, while Station 2 contained 77 particles. Meanwhile, the 1–5 mm size category made up 47%, with 105 particles in Station 1 and 54 in Station 2. The pie chart illustrating microplastic size distribution in corals at Penimbangan waters is shown in Figure 5.

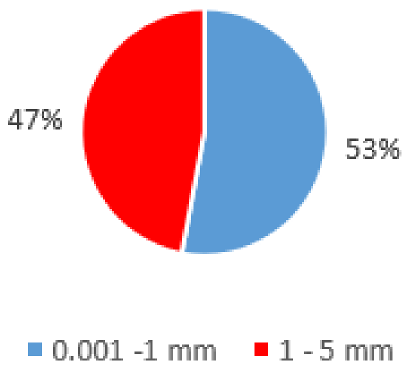

Figure 5. Pie Chart of Coral Microplastic Size in Penimbangan Waters

Five colors of microplastics were found in the corals of the Penimbangan Waters: black, blue, red, transparent, and brown. Black was the most commonly found color, with a total of 162 particles (48.5%), consisting of 92 particles at Station 1 and 70 particles at Station 2. Blue microplastics were found in 136 particles (40.7%), with 86 particles at Station 1 and 50 particles at Station 2. Red microplastics accounted for 30 particles (9%), with 23 at Station 1 and 7 at Station 2. Transparent microplastics totaled five particles (1.5%), with one particle at Station 1 and 4 particles at Station 2. Brown microplastics were the least found, with only one particle (0.3%) detected at Station 1. The histograms and pie charts illustrating the color distribution of microplastics in corals from the Penimbangan Waters are shown in Figure 6.

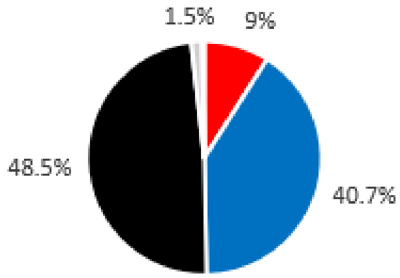

Figure 6. Pie Chart of Microplastic Color Percentage in the Reef of Penimbangan Waters

C. Discussion of Microplastics Abundance

In this study, the abundance of microplastics in corals from Penimbangan Waters was recorded at 1.95 ± 0.60 particles/g^{-1}. Several factors can influence the abundance of microplastics in corals. The first factor is the characteristics of the coral itself, as its ability to ingest microplastics depends on morphological variations such as feeding rate, physical size, resilience, and mucus production capability [36], [37]. The second factor involves the characteristics of the microplastics, including density, size, and shape, which determine the likelihood of microplastics reaching the coral and being ingested or trapped [16], [38]. The final factor is the condition of the research site, including pollution level, ocean currents, and surrounding anthropogenic activities [8].

Among the two sampling stations, the highest microplastic abundance was found at Station 1. This is likely due to its location being closer to tourist areas, with easier and more direct access from the beach, making it more vulnerable to tourist and recreational activities. These activities can generate plastic waste, which may degrade and break down into microplastic particles [41]. Previous studies have shown that the highest abundance of microplastics in corals is generally found at stations located within tourism zones, where recreational activities and human presence contribute to increased microplastic accumulation in coral reef ecosystems [8], [39], [40].

The abundance of microplastics in corals from Penimbangan Waters (1.95 particles/g^{-1}) was lower compared to coral samples from the Java Sea (Sambangan, Panjang, Bengkoang, and Geleang Islands), even in terms of microplastic shape abundance—except for granule-type microplastics, which were not detected in coral samples from the Java Sea. A comparison of microplastic abundance is presented in Table 1.

This study identified three types of microplastics in corals from the coral reef ecosystem of Penimbangan Beach, namely fibers (94.6%), fragments (5.1%), and granules (0.3%). Fiber microplastics, which are small plastic particles in the form of threads, are often the dominant type found in corals, as reported in several studies [44], [45]. The dominance of fiber microplastics in corals remains an open question. To date, no specific study has determined which microplastic shapes are most readily ingested by corals. However, predominance of fibers is likely due to their high abundance in surrounding waters and sediments [8]. Several studies on microplastics in Bali have also found fibers to be the most dominant or second most dominant form [24], [25], [46], supporting this assumption. However, further studies, including sampling of the surrounding water and sediment, are needed for confirmation.

TABLE 1
MICROPLASTIC ABUNDANCE COMPARISON

Location	Microplastic Abundance (Particlesl/g⁻¹)	Microplastic Abundance Fiber (Particle/g⁻¹)	Microplastic Abundance Fragment (Particle/g⁻¹)	Microplastic Abundance Granula (Partikel/g⁻¹)	Reference
Penimbangan Waters (karang)	1,95 ± 0,60	1,85 ± 0.6	0,09 ± 0.08	0.0057± 0.014	The Current Study
Panjang Island (Karang)	9 ± 0.62	3 ± 0.72	5 ± 1.47	-	[40]
Bengkoang Island (Karang)	4 ± 0.94	7 ± 2.53	7 ± 1.67	-	[40]
Geleang Island (Karang)	14 ± 2.14	4 ± 0.68	10 ± 4.11	-	[40]
Xisha Island (Karang)	1.3	-	-	-	[39]
Sri Lanka (Karang)	0.54 ± 0.17	-	-	-	[8]

In terms of transport mechanisms, fibers are more easily suspended in the subsurface water layer and carried by local currents, increasing their likelihood of reaching and accumulating in corals [Reichert *et al.,* 2022; Almeida *et al.,* 2023]. The sources of fiber microplastics in Penimbangan waters are suspected to include fishing activities, synthetic textile fibers, and tire wear. Fishing activities using gear such as nets and fishing lines made from synthetic fibers can degrade over time or be discarded into the sea [49]. Similarly, Kurniawan *et al.* (2021) found that fiber microplastics in the Karimunjawa Islands originated from fishing gear. Given the fishing activities in Penimbangan, there is a potential for fiber microplastics to enter the study area. Another suspected source is synthetic textile fibers, which are released during use and washing, generating fiber microplastics (Mishra *et al.,* 2019; Gago *et al.,* 2022). Indonesia is reportedly the second-largest contributor of fiber microplastics globally, mainly from the textile industry and laundering of synthetic textiles [51]. Therefore, the use and washing of synthetic textiles near Penimbangan Waters may be a major contributor. Additionally, tire wear contributes to the formation of microplastics, where abrasion or tire breakdown generates small, fiber-shaped plastic particles [52]. These particles are often transported by rainwater into rivers and eventually to the sea, as observed by Utami *et al.* (2023) in the Progo River, which drains into the Indian Ocean.

A similar situation is suspected in Penimbangan Waters, where a highway near a river discharging into the sea may act as a microplastic source. The second most dominant type of microplastic found in corals in the Penimbangan Waters is fragments. A similar dominance of microplastic shape has also been found in the Bali region [42]. These typically originate from the degradation of single-use plastics, such as plastic bags, bottles, and packaging materials [53]. Waste from such products around Penimbangan Waters, especially near residential areas and tourist beaches, is prone to degradation and thus may serve as a significant source of fragment microplastics. Additionally, fishing boats may contribute to the fragmentation of microplastics through the peeling of boat paint [54]. With many fishing vessels operating in this area, the potential contribution of paint-derived microplastic fragments is considerable.

The least common type of microplastic found was granules—small, rounded plastic particles (Jimenez *et al.,* 2024). These are suspected to enter the marine environment through domestic waste, including facial cleansers containing microplastic granules, which eventually flow into sewage systems and into the sea [56]. No film or foam microplastics were found in corals from Penimbangan Waters. This may be due to the physical characteristics of these types. Foam microplastics, typically made from lightweight materials like polystyrene, have low density and tend to float, making them less likely to reach corals at depth [57]. Film microplastics also exhibit similar behavior; their thin and lightweight form causes them to remain suspended or float in the water column (Archina, 2022).

Microplastics measuring 0.001–1 mm were the dominant size found in corals from Penimbangan Waters. This finding aligns with research in the Xisha Islands, where microplastics of a similar size range were also found to be the most prevalent [39]. Although there is no universally accepted standard on which microplastic size range is more likely to be captured or adhered to by corals, some studies suggest that smaller microplastics (0.001–1 mm) resemble the size of coral prey, such as plankton, and are thus more easily ingested [16], [58]. Furthermore, from a physical transport perspective, smaller particles are more easily carried by ocean currents. In marine environments, smaller microplastics (0.001–1 mm) are more prone to biofouling, which increases their density and accelerates sedimentation [38]. These factors combined allow small microplastics to remain suspended longer, travel farther, and eventually settle into coral reef ecosystems more easily than larger particles [59].

Microplastics in the 1–5 mm range were also found in the samples, but in lower quantities. According to Yen *et al.* (2024), microplastics of this size are less likely to be ingested by corals but may become trapped on coral surfaces or adhere to their structure. This size variation is the result of different degradation processes influenced by environmental factors. Exposure to ultraviolet (UV) radiation, temperature fluctuations, and ingestion by small organisms can accelerate the degradation of plastics. Moreover, the duration and intensity of degradation processes play a key role—prolonged and intense degradation leads to continuous breakdown of plastic into smaller particles [60], [61].

The colors of microplastics are derived from pigments or dyes added during the production of plastics [62]. As plastic products degrade, the resulting fragments typically retain their original color. However, exposure to UV radiation, abrasion, and environmental contamination can cause color fading or transformation [63]. At both stations, black microplastics were the most frequently found. According to Huang *et al.,* (2022), black microplastics originate from products that use black carbon pigment. This is consistent with findings from Flores Waters, where black microplastics dominated and were suspected to originate from the degradation of black-colored plastic products [64]. Given Penimbangan's proximity to settlements, anthropogenic sources such as black-colored plastic products, black textiles, and tire particles are likely contributors. Blue was the second most common color of microplastics found in corals at Penimbangan. This color is frequently observed in marine environments, especially in fishing areas, due to the degradation of blue fishing gear [59]. The third most common color was red, which is suspected to originate from red fishing gear or plastic items [65]. Transparent microplastics ranked fourth and may derive from explicit plastic materials [66] or fading of original colors [63]. Brown microplastics were the least abundant and may originate from brown plastics or contamination from the surrounding environment that altered the microplastic color [63].

IV. CONCLUSIONS

Based on the results and discussion, the average abundance of microplastics in corals in the coastal waters of Penimbangan Beach was recorded at 1.95 ± 0.60 particles per gram. The highest abundance of microplastics was found at Station 1, which is likely due to its proximity to tourist areas and the higher intensity of tourism activities. The characteristics of microplastics found in corals in the Penimbangan waters showed that the most dominant shape was fiber, followed by fragments and granules. The most commonly found microplastic size was in the 0.001–1 mm range, followed by the 1–5 mm size range. Meanwhile, black was the most dominant color of microplastics, followed by blue, red, transparent, and brown.

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