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Research Article

Macroplastic Characteristics and Assessment of the Plastic Abundance Index (PAI) of Beach Sediments in Prigi Bay, East Java, Indonesia

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Abstract

Macroplastics, defined as plastic debris ranging from 2.5 to 100 cm, pose significant threats to aquatic ecosystems, as they can breakdown into smaller particles. These materials are widely dispersed across marine environments, including coastal areas. This study aimed to compare and assess the abundance of macroplastics in the foreshore and backshore zones of four beaches around Prigi Bay, East Java, Indonesia, via the plastic abundance index (PAI). Macroplastics were collected via a 5×5 m quadrat transect method. The results revealed that single-use plastics, particularly packaging and sachets, dominated both zones, accounting for 86% and 91% of the total number of plastic items in the foreshore and backshore waste, respectively. The average abundance in the foreshore area was 0.71±0.21 items m^{-2} and 2.47±0.78 g m^{-2}, whereas that in the backshore area was significantly greater, at 1.59±0.40 items m^{-2} and 3.32 ±2.39 g m^{-2}. According to the PAI classification, the foreshore exhibited 'High Abundance' (PAI 4.1–8), whereas the backshore was categorized as 'Very High Abundance' (PAI > 8). These differences were attributed to human activity and environmental factors: the backshore, which is frequently used by tourists and less affected by wave action, accumulated a larger number of small, lightweight plastics, whereas the foreshore, which is exposed to tidal movements, contained fewer but larger and heavier macroplastics. The findings of this study underscore the importance of implementing targeted waste management strategies by identifying zones with the highest plastic accumulation and prioritizing the reduction of single-use plastics, especially packaging and sachets. These results can inform localized cleanup efforts, the placement of waste bins, and public education programs focused on areas with intense tourist activity, thereby mitigating macroplastic pollution and its environmental impact on both foreshore and backshore zones.

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Introduction

The rapid growth of the human population has led to numerous environmental challenges, including the increasing prevalence of pollution [1]. Among the various types of pollution, marine debris poses significant threats to ecosystems and human well-being. In addition to its ecological impacts, marine debris reduces the economic and aesthetic value of coastal and marine environments [2]. Defined as persistent solid material discarded or abandoned in coastal and marine areas [3], marine debris encompasses a wide range of materials, including plastics, glass, metal, textiles, rubber, paper, wood, cigarette butts, and other hazardous substances [4]. Among these types, plastic waste accounts for 60–85%

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of all marine debris, making it the most dominant and pervasive type [5].

Plastics are synthetic polymer materials characterized by long molecular chains and can be molded into various shapes and sizes through heating and forming processes [6]. Plastic debris is categorized into several size classes: megaplastic (>100 cm), macroplastic (2.5–100 cm), mesoplastic (5–2.5 cm), microplastic (1–5 mm), and nanoplastic (<1 μm) [7]. While significant attention has been given to microplastic pollution, research on macroplastics remains limited [8]. However, macroplastics are a critical concern, as they often degrade into microplastics, contributing significantly to microplastic pollution in marine environments. Therefore, assessing and monitoring the accumulation of macroplastic waste is essential for understanding and mitigating its environmental impact [9–10].

Coastal zones are particularly vulnerable to plastic pollution because of a combination of intense human activities, such as tourism, and natural processes, such as wave and current movements. These factors contribute to the high accumulation of plastic debris in these areas [11–12]. The coastal sedimentary environment is typically divided into two zones: the foreshore and the backshore. The foreshore, or intertidal zone, lies between the lowest and highest tide marks and is regularly exposed to tidal ebb and flow [13]. In contrast, the backshore extends from the highest tide line to areas of natural vegetation or artificial structures and is impacted only by waves during extreme weather events [14]. Human activities significantly influence plastic waste distribution in these zones [15]. The backshore is often associated with recreational activities such as picnicking, food vending, and walking, and it is affected by urbanization and development [16]. In contrast, the foreshore is typically used for water-based activities, such as swimming and water sports. These differing anthropogenic activities may lead to variations in the abundance and composition of plastic waste between the two zones.

Tourism-related activities are often associated with increased plastic waste in coastal zones [17]. Along the southern coast of Java Island, Trenggalek Regency features several attractive tourist destinations, particularly beaches within Prigi Bay [18]. This region, which is a hub for both tourism and fisheries, is home to the Fisheries Port (Pelabuhan Perikanan Nusantara, PPN) [19] and popular beaches such as Cengkrong, Prigi, Karanggongso, and Mutiara. The dual pressures from recreational and fishing activities make Prigi Bay especially vulnerable to plastic pollution. However, despite its ecological and economic importance, comprehensive data on the distribution, composition, and abundance of macroplastic waste in this area remain limited. This study assumes that local human activities, particularly tourism and fisheries, are among the dominant contributors to macroplastic accumulation. Therefore, this investigation focuses on quantifying macroplastic waste (2.5–100 cm) in the foreshore and backshore zones of selected beaches in Prigi Bay, as these areas are the primary interfaces between land-based activities and the marine environment.

This study aims to evaluate the abundance and composition of macroplastics in the foreshore and backshore zones of four beaches in Prigi Bay. Macroplastic abundance was assessed via the plastic abundance index (PAI), a metric that quantifies plastic pollution by analyzing the proportion of plastics relative to total marine debris [20]. By employing the PAI, this research seeks to provide valuable insights into the severity of plastic pollution and inform waste management strategies for coastal areas in Prigi Bay.

Materials and methods

The study was conducted in March 2024, with sampling carried out three times on consecutive weekends (Saturdays and Sundays). Weekend sampling was chosen because tourist activities on beaches are typically more concentrated during these days. The research focused on four beaches in the Prigi Bay area: Cengkrong Beach, Prigi Beach, Karanggongso Beach, and Mutiara Beach (Figure 1). These locations are located in Watulimo District, Trenggalek Regency, East Java Province [21]. Anthropogenic activities in the area, including fish landing, fishing, household waste disposal, ship maintenance, and tourism, significantly influence the level of waste pollution. Each beach also has distinct characteristics: Cengkrong Beach is adjacent to a mangrove area and has moderate tourist traffic; Prigi Beach is near a fishing port with high fishery-related activity; Karanggongso Beach is the most popular among tourists, with many vendors and facilities; and Mutiara Beach is quieter and surrounded by coastal vegetation. These varying profiles may influence the type and accumulation of macroplastic debris at each site.

1) Data collection

In this study, the collected data consisted of macroplastic waste and other organic and inorganic macrodebris. Macrodebris refers to all types of marine litter measuring between 2.5 and 100 cm, whereas macroplastic data specifically encompass all plastic waste within the same size range. Sampling was conducted in the foreshore and backshore zones of four tourist beaches in the Prigi Bay area (Figure 1). Marine debris collection followed the protocol established by the Ministry of Environment and Forestry of Indonesia (2020) and employed tools such as 5×5 m quadrat transects constructed using pegs and ropes, along with net bags for storing collected debris.

Quadrat transects were systematically placed along several lanes with 20 m intervals between each lane.

The number of transects per beach varies depending on the length of the coastline, with longer coastlines featuring more transects in areas of high anthropogenic activity. Once collected, the marine debris was cleaned, dried, sorted, and categorized via a classification table. Plastic waste can be classified into two categories: recyclable and single-use plastics. Recyclable plastics include items such as bottles, bottle caps, cups, and toys, whereas single-use plastics include straws, packaging materials/sachets, plastic cutlery, plastic bags, Styrofoam, cigarette butts, ropes, and similar items [23].

2) Data analysis

Macroplastics were analyzed for composition and abundance. Both macrodebris and macroplastic data were utilized to calculate the level of plastic abundance via the PAI. In this study, analyses included the total composition of plastics, the composition of recyclable and single-use plastics, and size distribution. The formula for calculating the composition of plastic waste is provided in Eq. 1 [22]:

$$\textbf{Composition} = \frac{\sum \textbf{Plastic per type}}{\sum_{1=1}^{n} \textbf{Xi}} \ \textbf{x 100\%} \quad \text{(Eq. 1)}$$

The weight and number of macroplastics collected from the backshore and foreshore zones of each beach were used to calculate plastic abundance. Abundance was analyzed via Eq. 2 [22].

$$\text{Abundance} = \frac{\text{Plastic weight/item}}{\text{Area (Length*Width)}} \ \text{x } 100\% \quad \text{(Eq. 2)}$$

The PAI, first introduced by Rangel-Buitrago et al. [20], provides a metric for determining the level of plastic abundance on beaches. This index calculates the relationship between the quantity of plastic items and the total number of litter items collected within a specific area. The PAI is calculated via Eq. 3.

$$\text{PAI} = \frac{\frac{\sum \text{Plastic litter items}}{\log_{10} \sum \text{Total litter items}}}{\text{Area (Length*Width)}} * \text{K}(20) \quad \text{(Eq. 3)}$$

On the basis of PAI measurements, beach conditions are categorized into five classes, ranging from "very low abundance" to "very high abundance" (Table 1).

Statistical analyses were performed via SPSS software version 26. The statistical evaluation of the plastic waste abundance data involved several stages, including a normality test, a homogeneity test, and either a t test or a Mann–Whitney test. The Mann–Whitney test, a nonparametric alternative to the t test, was used when the data did not meet parametric test assumptions [24]. A t test was used to analyze differences in the average abundance of macroplastics between the backshore and foreshore areas across the four tourist beaches in the Prigi Bay area.

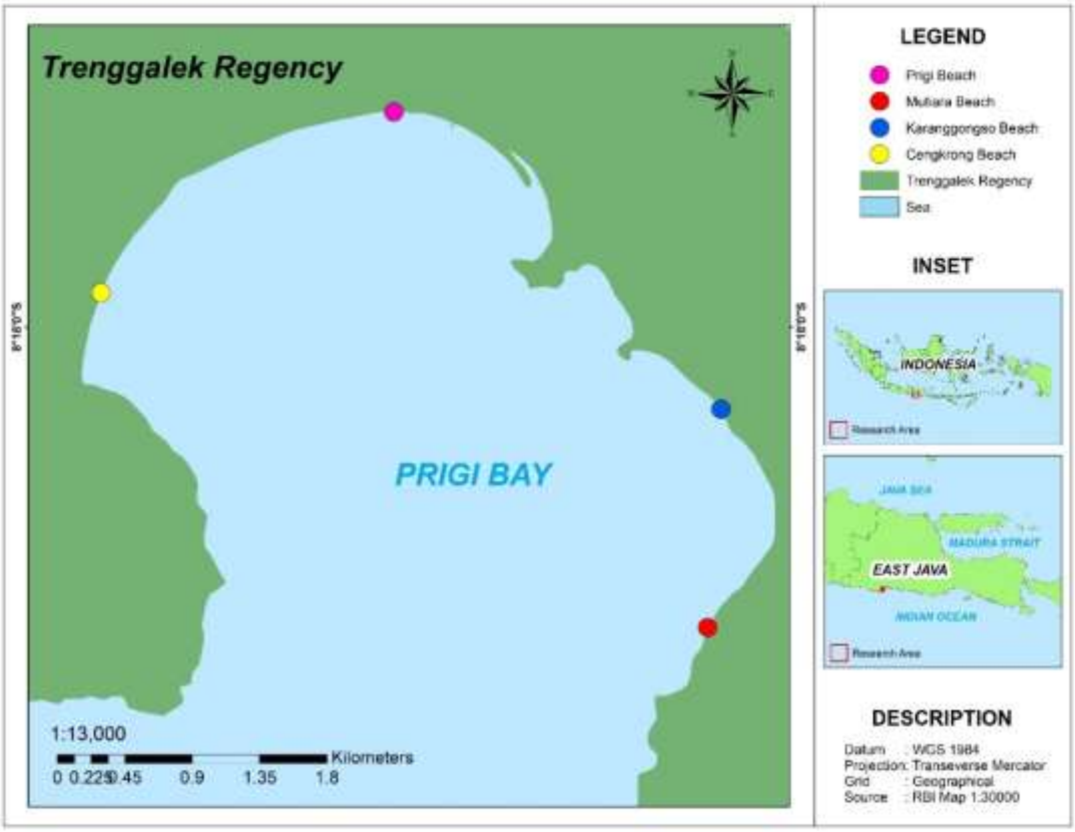


Figure 1 Research location.

Table 1 PAI result classification

PAI	Class	Description
0	Very low abundance/absence	No plastics are seen
0.1–1	Low abundance	Some plastics are in the sample area
1.1–4	Moderate abundance	A considerable amount of plastic is visible
4.1-8	High abundance	A lot of plastics are on the sample area
>8	Very high abundance	Most of the sampling area is composed by plastics

Source: Rangel-Buitrago et al. [20]

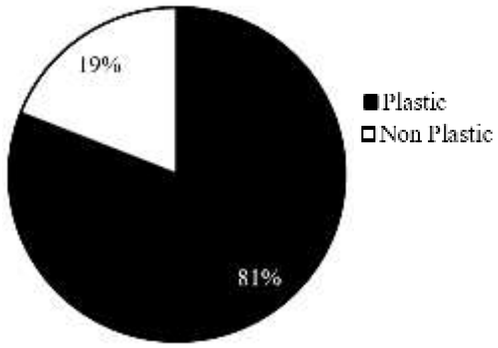
Results and discussion

1) Total composition of plastic waste

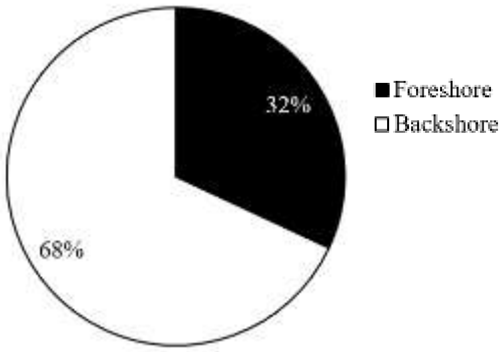
During the three sampling repetitions, a total of 6,504 marine debris items were collected, of which 81% (5,265 items) were plastic waste and 19% (1,239 items) were nonplastic waste (Figure 2a). The nonplastic waste category included materials such as paper, rubber, textiles, wood, metal, glass, ceramics, and hazardous and toxic waste. These findings align with those of Baxter et al. (2022), who reported that plastic waste constitutes 60–85% of total marine debris. Similarly, studies in other regions of East Java, Indonesia, such as Serang Beach, Blitar Regency, located on the southern coast near Prigi Bay, also revealed that plastic waste dominated, accounting for 75% of the total debris, followed by paper, rubber, and other materials [25]. On Gili Ketapang Island, located along the northern coast of East Java, plastic waste contributed 71% of the total waste, whereas nonplastic waste represented only 29% [26]. These locations were selected for comparison because of their geographical proximity and similar coastal activities, which provide relevant regional insight into plastic waste composition.

In this study, the quantity of plastic waste differed significantly ($P = 0.000$) between the backshore and foreshore areas. The backshore area contained 68% (3,583 items) of the total plastic waste, whereas the foreshore area contained only 32% (1,682 items) (Figure 2b). These findings are consistent with previous research, including studies conducted at Balekambang Beach [27], the Spanish coast [28], and the Strait of Malacca [23], all of which reported greater waste accumulation in backshore areas.

The greater abundance of waste in backshore areas can be attributed to tourism and fishing activities, which are more prevalent in these areas. At the study locations, tourists are predominantly engaged in activities in the backshore area, often leaving litter behind. Tourism activities in backshore areas significantly influence waste accumulation, as tourists frequently dispose of litter directly in coastal areas [28]. In contrast, the lower accumulation of waste in the foreshore area can be explained by the influence of waves and current movements, which may disperse and redistribute waste away from the sediment. This phenomenon has been described similarly by Bastesen et al. [15], who noted that hydrodynamic forces in foreshore zones reduce the accumulation of marine debris.



(a)



(b)

Figure 2 Graphs of (a) total composition of marine debris and (b) total composition of plastic waste in the two zones of the beach.

2) Composition of recyclable and single-use plastics

The plastic waste collected from each beach was categorized into two types: recyclable plastic and single-use plastic. Both the foreshore and backshore areas were predominantly composed of single-use plastic, accounting for 86% and 91% of the total plastic waste, respectively (Figure 3a and Figure 3b). Across all the research locations, single-use plastics consistently constituted 80–93% of the total plastic waste in both zones (Figure 3c).

The prevalence of single-use plastics at the research sites aligns with the findings of Pinheiro et al. [30], who reported that 95% of plastic debris consisted of single-use items such as plastic bags, straws, nets, drinking cups, and cutlery. Similarly, a high proportion of single-use plastics can also be found at Sendang Biru Beach

(84%) and PPP Pondok Dadap (90%). Single-use plastic waste is often associated with beach visitors, who leave it behind after recreational activities. The widespread use of single-use plastics is attributed to their practicality, affordability, lightweight design, waterproof properties, and hygienic characteristics [31].

Recyclable plastic waste at the study sites was classified into six categories: water bottles, bottle caps, drinking water glasses, children's toys, nonclear bottles, and miscellaneous items. Among these, bottle caps and drinking water glasses were the most dominant types of recyclable waste in both the foreshore and backshore areas (Figure 4a and 4b). The proportions of recyclable waste at the four beaches in Prigi Bay are shown in Figure 4c. Overall, the composition of recyclable plastic waste in both the foreshore and backshore zones across all beaches exhibited similar patterns, with bottle caps and drinking water glasses being the most dominant items. The high abundance of bottle caps can be attributed to several factors: they are typically found in dirty conditions and are often buried in sediments; their small size (2.5–5 cm) makes them difficult to collect during routine cleanups; and their high durability and resistance to decomposition allow them to persist in the environment for extended periods unless manually removed. This persistence poses significant threats to ecosystems and biodiversity [32]. Previous studies have reported the widespread presence of packaged drinking water waste, particularly in the form of glasses, bottles, and bottle caps [33], which are widely used because of their convenience and availability. However, a slight variation in the proportion of bottle caps was observed in the backshore zone of Karanggongso Beach, where the proportion was notably lower (25%) than those of the other beaches. This difference is likely associated with regular cleaning efforts carried out by local stalls and lodging owners, which may be more effective in removing such items from the beach environment.

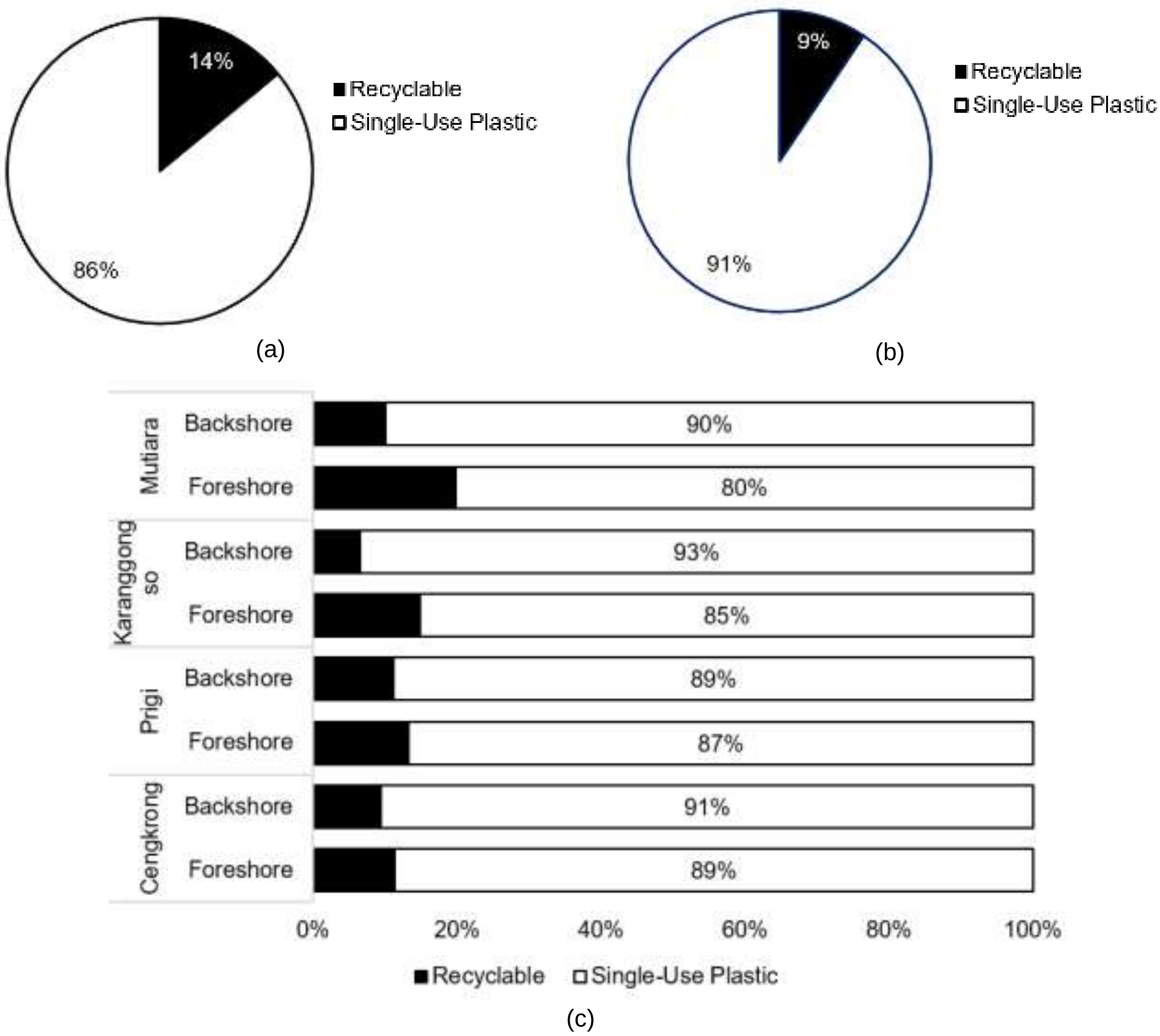


Figure 3 Composition of recyclable and single-use plastics on (a) foreshore, (b) backshore, and (c) four tourist beaches in Prigi Bay.

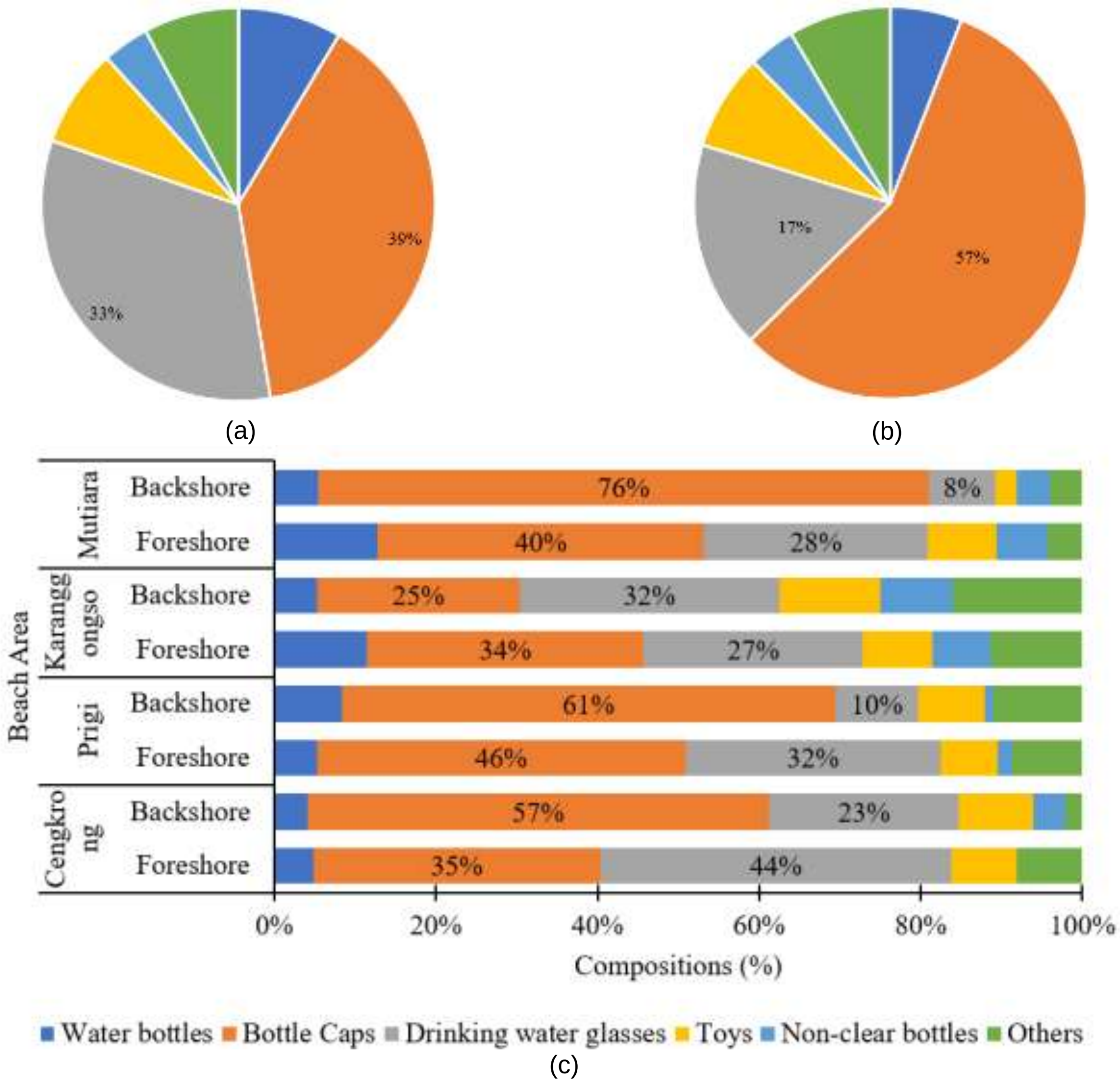


Figure 4 Composition of recyclable plastics on (a) foreshore, (b) backshore, and (c) four tourist beaches in Prigi Bay.

Single-use plastic waste can be categorized into five classes: straws, packaging/sachets, styrofoam, ropes, and others. The "others" category was further divided into three subcategories: clear plastic containers and cutlery, plastic bags, and cigarette butts. In both the foreshore and backshore areas, the "others" category dominated, accounting for 32% and 33% of the total waste, respectively, followed by packaging/sachets at 23% (Figure 5a) and 24% (Figure 5b). Across all the research locations, the dominance of "others" and packaging/sachets was consistent, except in specific areas such as the Cengkrong foreshore, where straws constituted 24%, and the Mutiara backshore, where styrofoam made up 34% (Figure 5c).

Packaging is also the most common waste type across 43 beaches along the Caribbean coast and Pacific waters [34]. This trend highlights poor waste management practices among local communities in Indonesia [35]. The types of plastic waste that accumulate in coastal areas often reflect the consumption habits of nearby populations. In the Prigi Bay area, packaging, straw, styrofoam, and ropes were identified as the predominant waste types, indicating significant usage of these materials by residents and visitors.

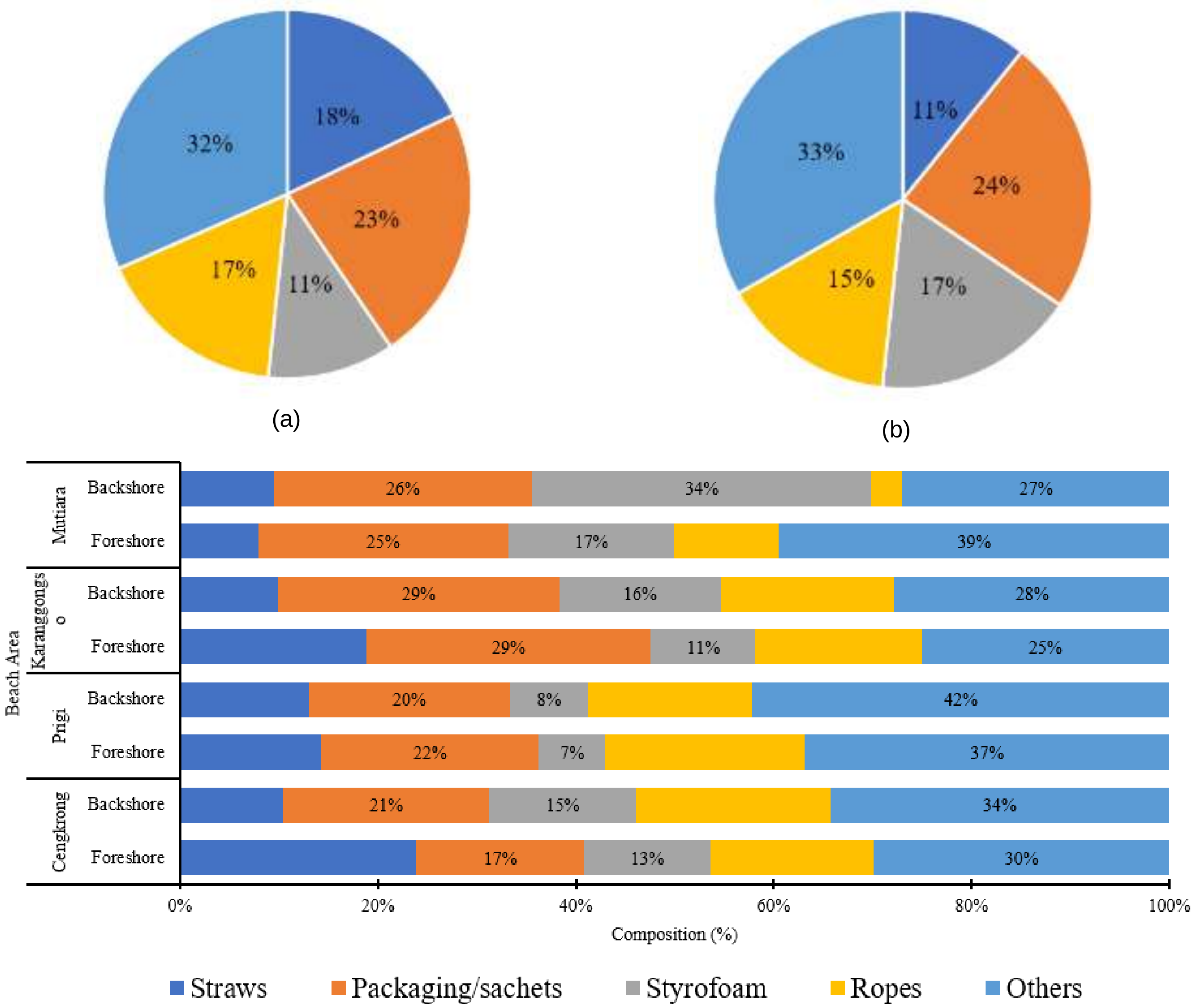
The abundance of rope waste, including fishing nets and related equipment, is closely tied to the active fishing industry along the coast. Over time, these materials degrade into microplastics, primarily in the form of fibers. Similar patterns were observed on the west coast of Situbondo, where fibers were the most frequently detected type of microplastic. These fibers are believed to originate from human activities such as laundry and the use of fishing nets. Owing to their small size and lightweight nature, fibers can be transported over long distances, contributing to widespread environmental pollution [36]. As modern lifestyles increasingly rely on convenience, the use of single-use plastics, including packaging and fishing-related materials, is expected to grow annually. This underscores the urgent need for policies aimed at reducing single-use plastic waste. Effective waste management systems and stricter regulatory measures are essential to mitigate the escalating environmental impacts associated with these plastics [33].

3) Size composition

Macroplastic waste collected in Prigi Bay can be categorized into three size classes: large macroplastics (10–100 cm), medium macroplastics (5–10 cm), and small macroplastics (2.5–5 cm). In both the foreshore and backshore areas, large macroplastics dominated, comprising 51% and 43% of the total waste, respect-tively (Figure 6a and Figure 6b). The size composition pattern across the research locations was consistent, with large macroplastics being the most prevalent, ranging from 42% to 55%. However, an exception was observed in the backshore area of Mutiara Beach, where medium-sized (40%) and small-sized (39%) macroplastics were more dominant (Figure 7).

The predominance of large macroplastics on the coast of Prigi Bay is attributed to the relatively new condition of the waste, which has not yet undergone significant environmental degradation. This pattern is observed in both the backshore and foreshore areas. In the backshore area, large macroplastics dominate because the transect is less influenced by environ-mental factors that promote waste degradation and is subject to relatively high levels of human activity [37]. Similarly, in the foreshore area, large macroplastics have a greater composition than other sizes do, as smaller macroplastics are more likely to become embedded in coastal sediments [38].

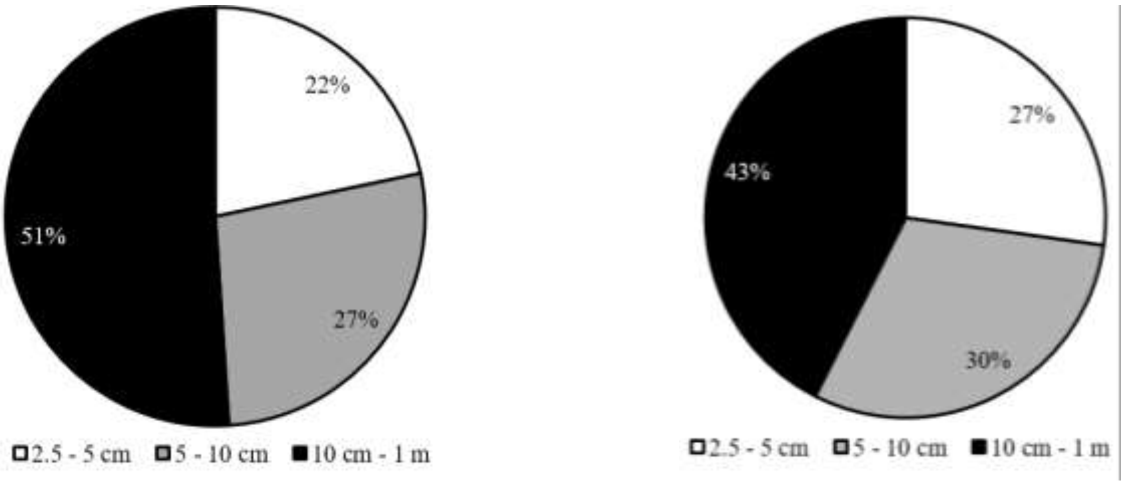
The dominance of medium and small macroplastics on Mutiara Beach, particularly in the backshore area, is attributed to debris becoming trapped and concealed within vegetation, making it less accessible during routine beach cleaning. Additionally, much of the waste on Mutiara's backshore is deposited in sediments. This phenomenon is supported by previous findings, which highlight that waste carried by wind to the backshore can be obstructed by vegetation and coastal structures, eventually becoming deposited and degraded in these areas [10, 37].



(a) (b)

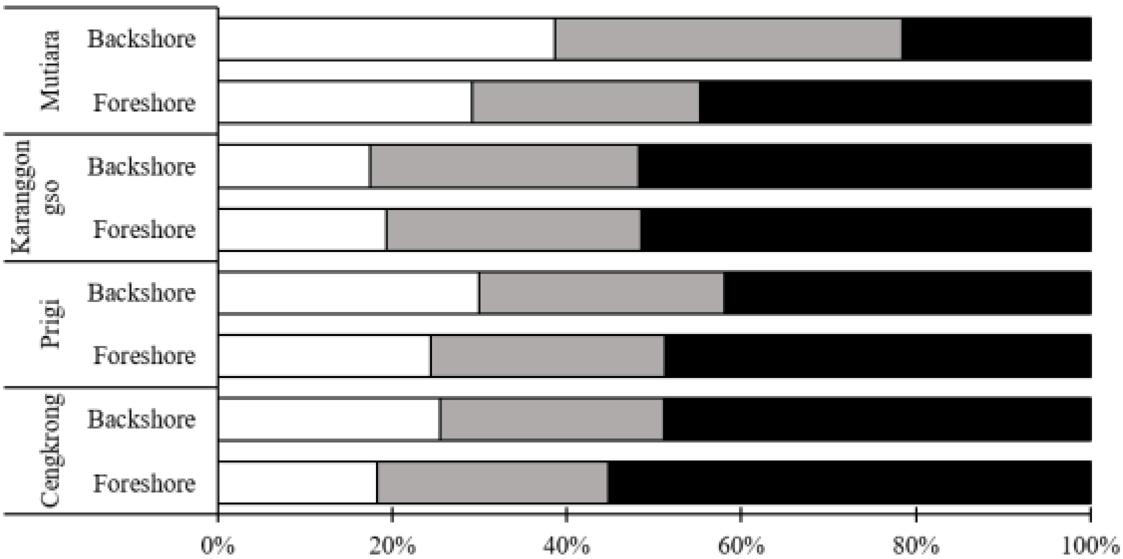
(c)

Figure 5 Composition of single-use plastics on (a) foreshore, (b) backshore, and (c) four tourist beaches in Prigi Bay.



(a) (b)

Figure 6 Macroplastic size composition on (a) foreshore and (b) backshore.



(c)

Figure 7 Macroplastic size compositions of the four beaches in the Prigi Bay area.

4) Number and weight abundance of plastic waste

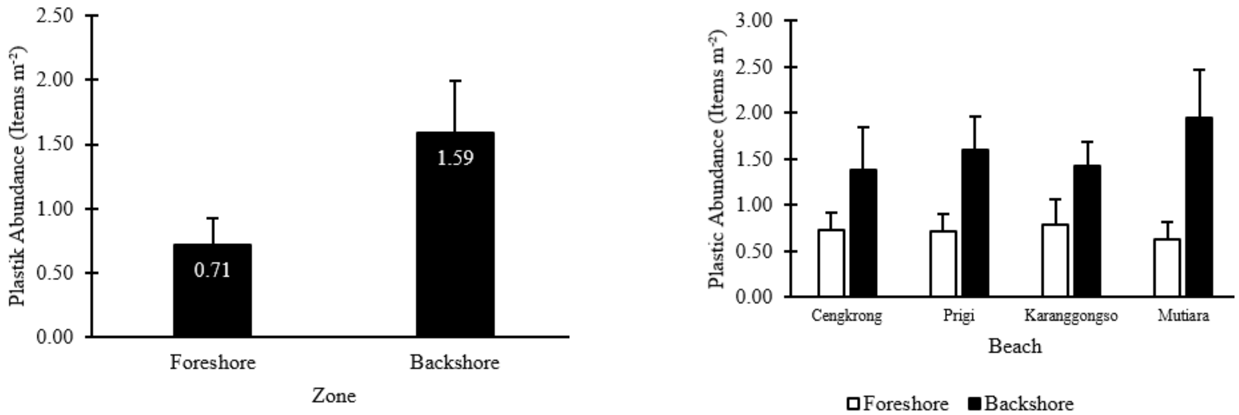
The average plastic abundance in the foreshore area was 0.71±0.21 items m^{-2}, whereas in the backshore area, it was 1.59±0.40 items m^{-2} (Figure 8a). Figure 8b presents the plastic waste abundance for each beach. Statistical analysis revealed a significant difference ($P = 0.005$) in the abundance of plastic waste between the foreshore and backshore areas.

The total weight of plastic waste collected from the four research locations was 13,982 g, with 5,896 g found in the foreshore area and 8,086 g in the backshore area. The average weight abundance in the foreshore area was 2.47±0.78 g m^{-2}, whereas in the backshore area, it was 3.32±2.39 g m^{-2} (Figure 9a). Statistical analysis revealed no significant difference in the plastic waste weight abundance between the backshore and foreshore areas of Prigi Bay ($P = 0.729$). The distribution of plastic waste weight at each beach is shown in Figure 9b.

Differences in the average abundance of both quantity and weight were observed between the foreshore and backshore areas. Significant differences in the quantity of waste were detected, whereas no significant difference in the abundance of weight was detected. In the backshore area, the quantity of waste was generally greater due to higher anthropogenic activities, such as tourism. The backshore area of Prigi Bay includes various tourism facilities, such as restaurants, snack vendors, children's playgrounds, and lodging. Despite the availability of trash bins at beaches such as Prigi and Mutiara, many visitors fail to dispose of their waste properly. The presence of tourists, coupled with poor beach management, contributes to increased plastic pollution [39]. Additionally, waste in the backshore area tends to be smaller in size, as routine beach cleaning primarily targets larger debris, leaving behind smaller items that accumulate in coastal sediments. Beach cleaning efforts were effective in removing larger debris, but smaller fragments often became buried in the sand and remained on the beaches for extended periods [40].

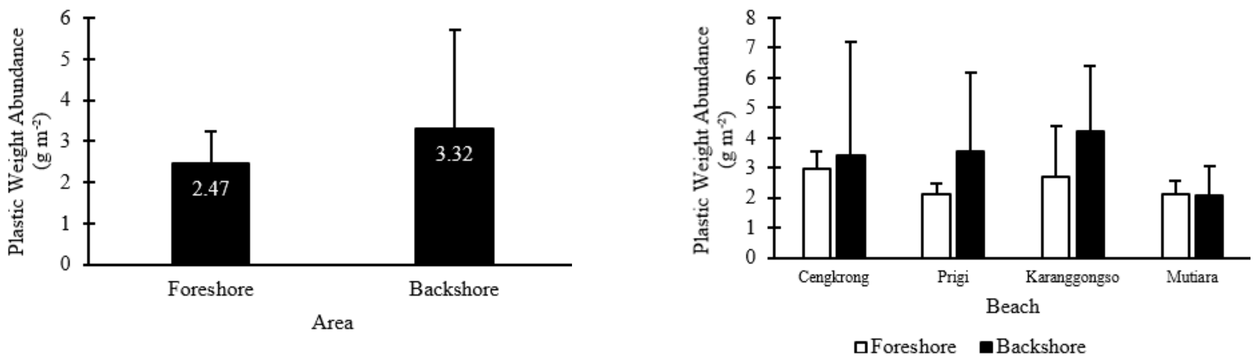
In the foreshore area, waste abundance was lower, but the waste present had a significant mass due to its larger size. This is likely because the foreshore experiences less human activity, and large debris accumulates when routine cleaning is lacking. The size of waste in the foreshore area can also be influenced by the movement of currents and waves, which can move small, lightweight debris away from the area [23]. This study did not focus on environmental factors such as wind speed, current patterns, and substrate shape, which are known to affect marine debris distribution [37]. Moreover, while this study emphasized plastic waste likely generated by local human activities such as tourism and fisheries, it is also possible that some debris found on beaches, particularly on foreshores, originated from distant sources and was transported by sea currents. This assumption was not tested in the present study, and future research is encouraged to incorporate hydrodynamic modeling to better differentiate between locally generated and externally transported waste.

Mutiara Beach showed the greatest variation in waste abundance between the two areas, with the backshore area having an abundance of 1.95±0.52 items m^{-2}, compared with only 0.63±0.18 items m^{-2} in the foreshore area (Figure 8b). In contrast, the weight abundance at Mutiara Beach had minimal variation, with values of 2.09±0.99 g m^{-2} in the backshore and 2.10±0.46 g m^{-2} in the foreshore (Figure 9b.). The backshore waste at Mutiara Beach consisted mostly of medium and small macroplastics (Figure 7), dominated by styrofoam and bottle caps (Figure 5c), which have relatively light masses. These findings suggest that the abundance of waste in the backshore area of Mutiara Beach likely results from the fragmentation of larger debris. The relationship between the number of waste items and their mass is not always proportional [41]. For example, waste such as plastic bags, ropes, and containers tends to have a direct relationship with quantity and mass, whereas other items such as packaging, bottle caps, styrofoam, straws, and glasses may not have the same correlation. Styrofoam, in particular, is prone to fragmentation into smaller particles due to weathering and degradation [42]. Its lightweight nature also allows it to be carried by the wind to the backshore area [14]. Additionally, the backshore area of Mutiara Beach is influenced by the presence of vegetation, which traps plastic waste and prevents it from moving further inland. Waste carried by the wind is often blocked by vegetation and coastal walls, leading to accumulation and sedimentation in the backshore area [37]. Waste in these areas can degrade over time, further contributing to smaller waste particles [10].



(a) (b)

Figure 8 Plastic item abundance in (a) coastal zones and (b) beaches.



(a) (b)

Figure 9 Plastic weight abundances of (a) coastal zones and (b) beaches.

5) Plastic abundance index (PAI)

In general, the average PAI value for the foreshore area of Prigi Bay was 5.99±1.40, categorizing it as 'High abundance' (PAI range: 4.1–8), whereas the PAI value for the backshore area was 12.46±2.70, placing it in the 'Very high abundance' category (PAI >8). Visualization of the PAI values can be found at Figure 10. All the tourist beaches in the foreshore area were classified as 'High abundance', whereas those in the backshore areas were categorized as 'Very high abundance'.' These results indicate that both areas of Prigi Bay contain significant amounts of plastic waste [43].

The PAI value increases with the abundance of plastic waste, which is evident in the higher PAI observed in the backshore area. The factors contributing to this disparity include anthropogenic activities, marine hydro-oceanographic parameters, and waste management practices at the research locations [37]. While the index assessment reflects the abundance in the transect area, it is important to note that, visually, plastic waste does not cover the entire coastline, particularly in the foreshore area, where waste abundance is lower.

The average PAI values from the Cengkrong, Prigi, Karanggongso, and Mutiara Beaches were compared with data from six other studies in different regions (Table 2). The PAI values for Prigi Bay coast were found to be greater than those reported for Okinawa Island, Japan; Morocco; and Maranhão Bay, Brazil [32, 44–45]. In contrast, the PAI values at Playa Blanca Beach in Colombia and Guacalillo Beach in Costa Rica were similar to those of the four beaches in Prigi Bay, both falling within the 'very high abundance' category [20, 46]. This comparison underscores that Prigi Bay beaches have a notably greater plastic abundance than many other global locations do. The application of the PAI allows for a more detailed classification of plastic waste abundance, providing valuable insights for public administrators to implement targeted measures aimed at reducing pollution. The deposition of plastic waste on beaches significantly impacts the environment and marine organisms and poses economic risks to local communities [44].

The high abundance of plastic waste in coastal areas poses significant risks to both the fisheries and tourism sectors and disrupts the balance of the local ecosystem [47–49]. When macroplastics remain in the environment for prolonged periods, they can degrade into micro-plastics. These smaller particles accumulate in aquatic environments and are becoming increasingly difficult to remove. Their widespread presence is driven primarily by human activities and sources of pollution. Microplastics can also serve as carriers for toxic and carcinogenic chemicals, further exacerbating environmental hazards. Additionally, microorganisms often colonize microplastics, transforming them into reservoirs and pathways for the spread of harmful pathogens [50].

To mitigate these challenges, it is essential to implement effective policies, regulations, and waste management practices. Reducing the amount of plastic produced, particularly single-use plastics, is crucial for minimizing the amount of plastic waste entering coastal environments [32]. Regular beach cleaning initiatives, alongside increased public awareness and education on plastic waste management, can further help reduce the plastic burden on beaches [31].

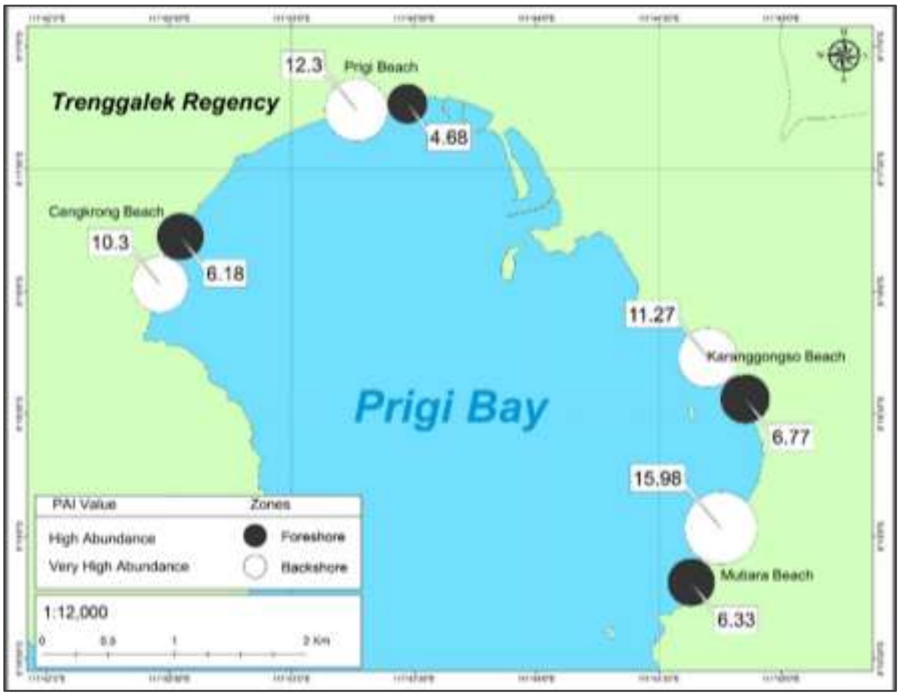


Figure 10 PAI abundance in the foreshore and backshore areas.

Table 2 Comparison of the PAI value and waste abundance

Location	Waste abundance (items m^{-2})	PAI	PAI classification	Reference
Cengkrong Beach, Trenggalek Regency	2.11±0.33	8.24±2.16	Very high abundance	This study
Prigi Beach, Trenggalek Regency	2.32±0.27	8.49±1.82	Very high abundance	This study
Karanggongso Beach, Trenggalek Regency	2.21±0.27	9.02±1.80	Very high abundance	This study
Pearl Beach, Trenggalek Regency	2.58±0.35	11.16±2.41	Very high abundance	This study
Colombia	4.54	24	Very high abundance	[20]
Okinawa Island, Japan	0.13±0.10	1.12	Low abundance	[32]
Morocco	0.31±0.45	1.49	Low abundance	[45]
Playa Blanca Beach, Costa Rica	1.4	8.9	Very high abundance	[46]
Guacalillo Beach, Costa Rica	2.2	14.9	Very high abundance	[46]
Gulf of Maranhão, Brazil	0.16	1.04	Low abundance	[44]

Conclusions

On the basis of the findings of this study, the plastic waste compositions in the foreshore and backshore areas of Prigi Bay are not significantly different. Both areas are dominated by single-use plastics and large macroplastics (10 cm–100 cm). This suggests that the waste found in both areas likely originates from the same source, primarily from tourism activities. The types and sizes of waste are consistent across these regions, further supporting the notion that they are influenced by similar human activities.

When the abundance of plastic waste was examined, a significant difference was observed in the number of items between the foreshore and backshore areas, but no significant difference was found in the weight of the waste. This can be explained by the different characteristics of the plastic waste found in each area. In the backshore area, more waste is scattered, and it tends to be smaller and lighter in size. On the other hand, the foreshore area contains less waste, but it is larger, contributing to a greater mass. The backshore area, which experiences more human activity, accumulates more plastic waste, although beach cleaning efforts result in less debris being left behind. In contrast, the foreshore area experiences less accumulation due to lower tourist numbers, oceanographic factors, and fewer cleaning activities.

The PAI reveals that the foreshore area of Prigi Bay falls under the "High abundance" category, whereas the backshore area is classified as "Very high abundance." These differences in abundance are influenced by factors such as tourism activities, beach cleaning practices, and hydrooceanographic conditions. Overall, the results of this study indicate that both the foreshore and backshore areas of Prigi Bay are heavily polluted by plastic waste, with significant environmental implications for coastal ecosystems.

Importantly, this study did not assess the potential contributions of ocean currents or other hydrodynamic factors in transporting debris to the studied sites. Future research should include such environmental variables to distinguish between locally sourced and externally transported macroplastic waste, thereby providing a more comprehensive understanding of plastic pollution dynamics in coastal areas.

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