Beach Cleanliness and Marine Debris Characteristics for Sustainable Coastal Tourism in Prigi Bay, Indonesia

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Abstract

Tourist activity significantly impacts coastal ecosystems, often leading to increased marine debris pollution. This study examines the influence of tourism on beach cleanliness by analyzing marine debris composition, abundance, and Clean Coast Index (CCI) at four recreational beaches in Prigi Bay, Trenggalek, Indonesia (Cengkrong, Prigi, Karanggongso, and Mutiara). Sampling was conducted in March–April 2024, using a 5×5 m quadrat transect method placed at 20 m intervals along the shoreline in the backshore zone. The Mann-Whitney U test was applied to assess differences in debris accumulation between weekdays and weekends. Results indicated that plastic debris was the dominant type across all sites, with debris abundance slightly higher on weekends (54%) than weekdays (46%). Moreover, the mass of accumulated debris was significantly greater on weekends (1.93 items.m $^{-2}$, 8.86 g.m $^{-2}$) than on weekdays (1.57 items.m $^{-2}$, 4.69 g.m $^{-2}$), primarily due to an increase in larger debris items (10–100 cm), likely associated with tourism-related waste such as food packaging and recreational items. Despite these fluctuations, all beaches exhibited "extremely dirty" CCI scores (>20), indicating persistent pollution beyond tourism activity. Additional contributing factors may include inefficient waste management, fishing-related debris, and marine transport mechanisms. These findings underscore the urgent need for comprehensive waste management strategies, including source reduction, regular cleanups, improved waste disposal infrastructure, and public awareness campaigns, to mitigate long-term environmental and socio-economic impacts in Prigi Bay. Furthermore, integrating this measure into sustainable coastal tourism planning is crucial to balance recreational use with environmental preservation.

Keywords: *Pollution, Tourism, Beach Cleanliness, Environmental Assessment, Waste Evaluation*

Introduction

Marine debris, which is a common form of solid waste, presents a global challenge (Anna *et al*., 2022). This debris consists of materials that are intentionally or unintentionally discarded into the sea (Yona *et al*., 2019; Johan *et al*., 2020) and is widespread in the marine environment. It can be found floating on the surface, submerged at the seabed, or stranded along coastlines due to activities on land (Dwiyanto, 2011; KLHK, 2020). Despite its stunning archipelagic beauty and growing tourism industry (Kurniawan *et al*., 2016; Ashuri and Kustiasih, 2020), Indonesia is not exempt from this issue. Data collected over 25 years by Ocean Conservancy activities in various countries emphasize the unfortunate link between tourism and increased pollution levels (Attamimi *et al*., 2015; Anna *et al*., 2022).

Human activities have a substantial impact on beach cleanliness, with differences in these activities between weekdays and weekends influencing travel behavior (Manullang *et al*., 2014). This travel behavior includes both daily and non-daily activities, with some activities being done regularly and others being reserved for weekends (Manullang *et al*., 2014; Muthahharah and Adiwibowo, 2017). Research conducted at Watu Ulo Beach in Jember Regency shows that there is a peak in tourist numbers on weekends (Saturday and Sunday) and a notable decline on Mondays (Wati and Sudarti, 2021). This observation is consistent with findings from studies in Florida, Spain, and the Northwestern Mediterranean Coast (Bell and Leeworthy, 1990; Sardá *et al*., 2009; Toubes *et al*., 2024). It is well-documented that there is a correlation between increased tourist presence and higher levels of marine debris on beaches (Cordova *et al*., 2021; Maione, 2021; Wati and Sudarti, 2021).

Ensuring coastal cleanliness is essential for preventing long-term environmental degradation (Amri *et al*., 2023). The Clean Coast Index (CCI) serves

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as a valuable tool for guiding preservation efforts by quantifying the overall waste density per square meter. This facilitates objective assessments of coastal ecosystem health (Alkalay *et al*., 2007; Yona *et al*., 2023). The CCI's straightforward implementation, objectivity, and applicability to various marine debris types make it a versatile instrument for coastal management (Rangel-Buitrago *et al*., 2019a; 2019b). Consequently, the CCI has been widely adopted for coastal cleanliness assessments in numerous global studies (Suteja *et al*., 2021; Lim *et al*., 2021; Manullang *et al*., 2021; Hayati *et al*., 2022; Poluan *et al*., 2023; Yona *et al*., 2023; Heravi *et al*., 2024).

The Regional Spatial Planning (RTRW) for 2011–2021 highlights Trenggalek Regency as an area with significant marine tourism potential, as evidenced by the scenic Prigi Bay and the presence of East Java's largest fish market (Moira *et al*., 2020). However, increased tourism activity poses potential environmental challenges, particularly in the form of marine debris accumulation on recreational beaches. This study specifically focuses on the backshore zone of Prigi Bay, where samples were collected on both weekdays and weekends to account for fluctuations in tourist numbers. Given that tourist activity typically peaks on weekends, it is expected that the quantity and mass of marine debris will be significantly higher on weekends compared to weekdays (Bibin and Ardian, 2020; Wati and Sudarti, 2021).

Therefore, this study aims to analyse the characteristics of marine debris and evaluate its accumulation patterns over different timeframes. Specifically, we hypothesize that there is a significant difference in the abundance and mass of marine debris between weekends and weekdays, with higher accumulation occurring on weekends due to increased visitor activity. Additionally, this study expects variations in the type and composition of debris based on tourism-related and local sources. We anticipate that plastic debris, particularly large microplastics, will be the dominant type of waste, as plastics are commonly used in tourist-related activities and are highly persistent in the environment. Other significant debris types may include paper and wood-based materials, often associated with food packaging and beachgoer activities. Conversely, on weekdays, debris composition may include a higher proportion of locally generated waste, such as fishing-related debris from nearby communities. To assess these patterns, the Clean Coast Index (CCI) was employed, as it objectively quantifies marine debris density per square meter and has been proven effective in evaluating coastal cleanliness, particularly in tourism-heavy areas. The findings of this study are expected to contribute to a better understanding of marine debris patterns and support evidence-based management strategies for mitigating coastal pollution in Prigi Bay and similar environments.

Materials and Methods

Prigi Bay, located in the Watulimo District of Trenggalek Regency, East Java, lies along the southern coast of Java facing the Indian Ocean. The region is characterized by hilly and mountainous terrain, creating a scenic coastal landscape. According to the Trenggalek Regency Regional Spatial Plan (RTRW) 2011–2021, Prigi Bay is a key maritime tourism destination, offering recreational activities, ecotourism, and housing the Prigi Nusantara Fisheries Port (PPN Prigi). Its well-developed road network further enhances accessibility for tourists. However, various anthropogenic activities, including fishing, household waste disposal, and boat maintenance, contribute to pollution in the area. Sampling locations were selected based on the intensity of these activities. This study focuses on beaches with similar tourism characteristics but differing daily activities due to variations in environmental conditions and management practices.

Data collection and analysis

The research was conducted over a period from March 16 to April 3, 2024, at the recreational beaches of Prigi Bay, Trenggalek, Indonesia, covering four specific beaches: Cengkrong, Prigi, Karanggongso, and Mutiara (Figure 1). The data collection involved three repetitions to compare the differences between weekdays and weekends. The focus of the sampling was on the backshore zone, which is recognized as the area most significantly impacted by tourism activities (Kaviarasan *et al*., 2022; Setyawan, 2011). Sampling was conducted using a 5×5 m quadrat transect, which was systematically placed at 20 m intervals along the shoreline at each beach (Yona *et al*., 2023). A 5×5 m quadrat provides an optimal balance between fieldwork efficiency, representativeness, and feasibility. While larger quadrats could improve accuracy by capturing a broader area, they would also require significantly more time and effort per sampling unit, limiting the number of replicates that can be conducted. Multiple quadrats were deployed at each location to ensure adequate spatial representation, and the 20 m interval between transects was chosen to minimize spatial autocorrelation while capturing variability in debris distribution along the beach. This approach allowed us to account for heterogeneous debris distribution while maintaining methodological consistency across sites.

Marine debris is classified according to its material composition, including plastic, rubber, paper, textiles, wood, metal, glass, ceramics, and other materials. This study further categorizes the marine debris into three size ranges: small macro (2.5 – 5 cm), medium macro (5–10 cm), and large macro (10–100 cm) (Yona *et al*., 2023). Marine debris composition percentage can be count by counting the amount of debris at each type per total waste in the transect according to Equation 1 (KLHK, 2020).

$$Marine\ debris\ composition\ (\%) = \frac{number\ of\ type\ of\ debris}{total\ number\ of\ debris} x\ 100\% \quad (1)$$

Marine debris abundance was quantified by both count and mass (Equation 2). Transect area, calculated as transect length multiplied by width, served as the denominator for determining debris density. The transect length was determined based on the shoreline length of each surveyed beach, ensuring that the sampling areas were proportional to the beach size. Abundance was expressed as items per square meter (items.m^{-2}) and grams per square meter (g.m^{-2}), following standard methodologies (KLHK, 2020).

$$Abundance\ = \frac{total\ number\ of\ debris\ (items\ and\ grams)}{transect\ area\ (m^2)} \quad (2)$$

The Clean Coast Index (CCI) is utilized to assess the state of coastal cleanliness (Alkalay *et al*., 2007). The CCI has been demonstrated to be effective in enhancing cleanliness in coastal ecosystems. The data collected are analyzed using Equation 3 and the results are then classified into various categories of cleanliness according to Table 1 (Alkalay *et al*., 2007).

$$CCI\ = Debris\ abundance\ x\ k \quad (3)$$

k is a constant that is equal to 20.

Table 1. CCI Categories

CCI	Class	Description
0-2	Very Clean	*No litter is seen*
2-5	Clean	*No litter is seen over a large area*
5-10	Moderately Clean	*A few pieces of litter can be detected*
10-20	Dirty	*A lot of waste on the shore*
>20	Extremely Dirty	*Most of the shore is covered with marine debris*

Source: (Alkalay *et al*., 2007)

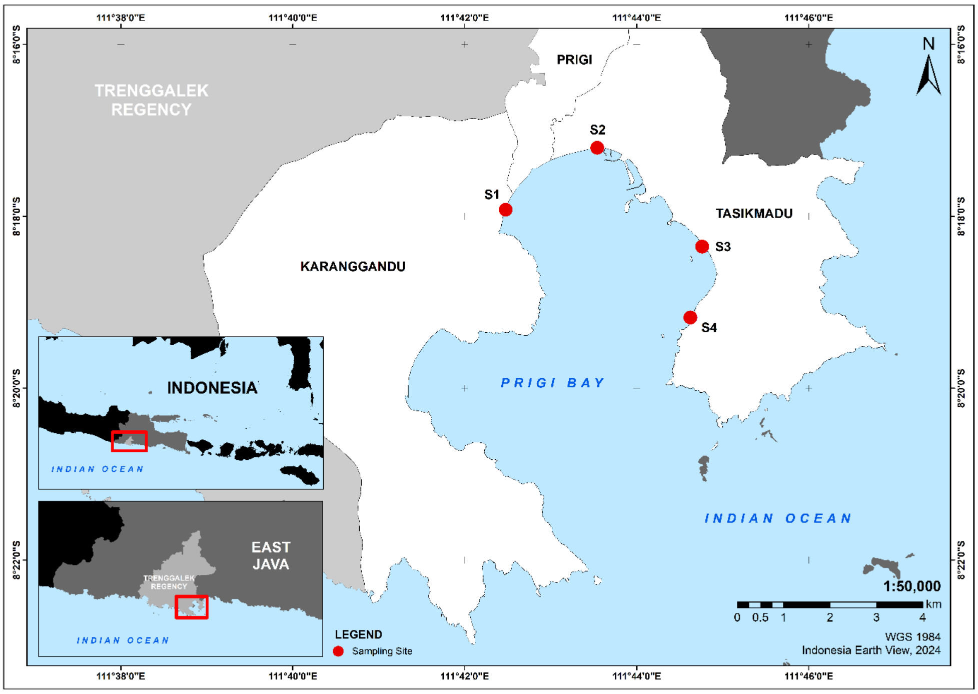

Figure 1. Sampling location in the Prigi Bay consists of four beaches: S1: Cengkrong Beach; S2: Prigi Beach; S3: Karanggongso Beach; S4: Mutiara Beach

To assess differences in marine debris abundance between weekdays and weekends, a non-parametric statistical test, Mann-Whitney U test was applied to compare two independent groups. This test was chosen because the data did not meet the assumptions of normality and homogeneity of variance, making non-parametric methods more appropriate than parametric alternatives such as the t-test or ANOVA. The Mann-Whitney U test evaluates whether the distribution of values differs between the two groups, providing a robust measure of statistical significance ($p < 0.05$). Statistical analyses were performed using IBM SPSS Statistics 2.6.

Result and Discussion

Marine debris sampling was conducted at four popular tourist beaches within Prigi Bay: Cengkrong (Karanggadu Village), Prigi, Karanggongso, and Mutiara (Tasikmadu Village). While all beaches serve as tourist destinations, Prigi Bay's coastal region is particularly affected by anthropogenic activities. Fishing, waste disposal, tourism, and other human-related activities contribute significantly to marine debris pollution. The strategic location of Prigi Bay, including the presence of the national fishing port and the largest fish auction place in southern Java, underscores the importance of fishing as a key factor influencing beach conditions and the local community.

Composition of marine debris

The percentage of marine debris was calculated based on the total data collected from four study locations over three repetitions. A total of 8,122 items of marine debris were found, with 3,698 on weekdays and 4,424 on weekends, representing 46% and 54% of the total debris, respectively. Statistical analysis revealed a key finding that there was no significant difference in the total amount of marine debris between weekdays and weekends ($P>0.05$). This lack of variation can be attributed to the consistently high level of anthropogenic activities in the Prigi Bay Tourism Beach Area, including household activities, fishing, and tourism. This finding has significant implications for future research, as it suggests that continuous pollutant input from human activities can obscure any potential differences in marine debris accumulation between weekdays and weekends (Yona *et al*., 2020; Zaman *et al*., 2023).

Analysis of marine debris composition revealed a predominance of plastic items at Prigi Bay Tourism Beach Area (Figure 2A). On weekdays, plastic debris constituted 88% of the total (3,272 out of 3,698 items), with the remaining 12% comprising non-plastic materials. Similarly, on weekends, plastic debris accounted for 81% of the total (3,583 out of 4,424 items), while non-plastic debris represented 19%. The analysis of marine debris across the four beaches and both day categories (Figure 2B, 2C) revealed a consistent predominance of plastic waste, exceeding 80% of the total debris. This prevalence, observed on both weekdays and weekends, reflects the ubiquitous use of plastic materials in human activities. The types of plastic debris identified at Prigi Bay Tourism Beach Area included ropes, cutlery, straws, cigarette butts, styrofoam, packaging, and other miscellaneous items. This dominance of plastic waste in marine debris aligns with findings from studies conducted in diverse coastal regions (Rangel-Buitrago *et al*., 2019a; 2019b; Hayati *et al*., 2020; Manullang *et al*., 2021; Akarsu *et al*., 2022; Pervez and Lai, 2022; Silva *et al*., 2022; Ciufegni *et al*., 2024; Salinas *et al*., 2024; Yona *et al*., 2024).

Marine debris was categorized based on its constituent materials, including plastic, rubber, paper, textiles, wood, metal, glass, ceramics, and other miscellaneous items. Analysis of debris composition at Prigi Bay Tourism Beach Area (Figure 3) revealed a distinct pattern. On weekdays, plastic waste was the most prevalent, comprising 89% of the total debris, followed by paper (4%), other materials (3%), rubber (2%), and hazardous waste (2%). A similar trend was observed on weekends, with plastic again dominating at 82%, followed by paper (7%), other materials (4%), wood (3%), rubber (2%), and hazardous waste (2%). The "other materials" category encompassed items with individual percentages below 3%, including textiles, metal, glass, and ceramics. Overall, the results indicate that after plastic, the most prevalent debris categories were paper, followed by the combined "other materials" category, rubber, and lastly, hazardous waste.

The observed increase in the proportion of wood and paper waste on weekends (Figure 3B) is likely linked to heightened tourism activities. This surge can be attributed to waste generated by tourists, which encompasses materials beyond plastics. Common examples of paper waste found in the study area included tissues, cigarette packaging, rice paper, and food packaging, while wood waste primarily consisted of food sticks and ice cream sticks. Furthermore, other studies have also highlighted the prevalence of paper and wood waste, in addition to plastic, in tourism areas, often followed by food and metal waste (Kumar *et al*., 2016; Zaman *et al*., 2023). This suggests a consistent pattern of waste generation associated with recreational activities in coastal environments.

While our study identifies tourism activity as a primary driver of marine debris accumulation, we acknowledge that other potential sources, such as fishing activities, illegal dumping, and riverine inputs, may also contribute to the presence of debris in the study area. The dominance of macroplastic, paper, and wood-based materials, particularly on weekends, strongly suggests a tourism-related waste influx; however, debris from fishing gear (*e.g.*, nets, ropes, and floats) was also observed, indicating that fishing activities could be an additional contributing factor. Moreover, riverine inputs serve as a known pathway for land-based waste entering coastal environments (van Emmerik *et al.*, 2019; Harris *et al.*, 2021). Although our study did not specifically assess the contribution of upstream waste sources, the potential influence of rivers and drainage systems in transporting debris to the study beaches cannot be ruled out. Similarly, illegal dumping in coastal areas, either by local residents or transient visitors, may add to the complexity of marine debris sources.

Marine debris in this study was categorized into three size classes: small macro (2.5–5 cm), medium macro (5–10 cm), and large macro (10–100 cm). Analysis of the size distribution of marine debris at Prigi Bay Tourism Beach Area (Figure 4) indicated a predominance of large macro debris. On weekdays, large macro debris constituted 42% of the total, followed by small macro debris (30%) and medium macro debris (28%). A similar pattern was observed on weekends, with large macro debris again being the most prevalent (45%), followed by medium macro debris (31%) and small macro debris (24%). These findings highlight the significant contribution of large-sized debris to the overall marine debris pollution at the study sites.

The predominance of large macro debris (>10 cm) suggests a significant input of recently deposited waste that has not undergone substantial degradation. The rate and extent of debris degradation are influenced by various factors, including the characteristics of the material, shape, density, and prevailing environmental conditions (Rodrigues *et al.*, 2019). In this study, the dominance of large macro debris is likely attributable to the sampling location within the backshore zone. This

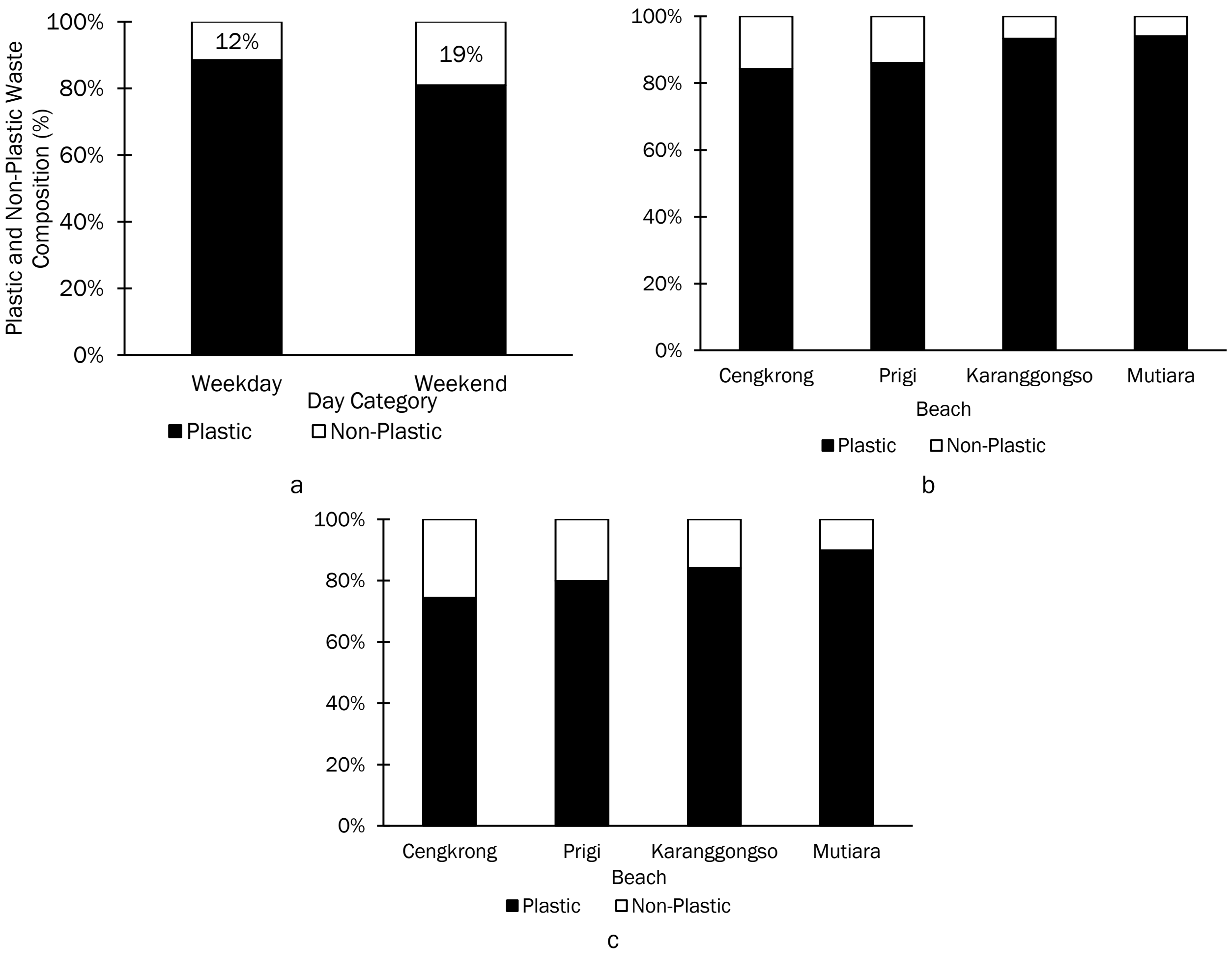

Figure 2. Composition of Plastic and Non-Plastic Waste in all sampling beaches (A), and the composition in each beach in Weekday (B) and Weekend (C)

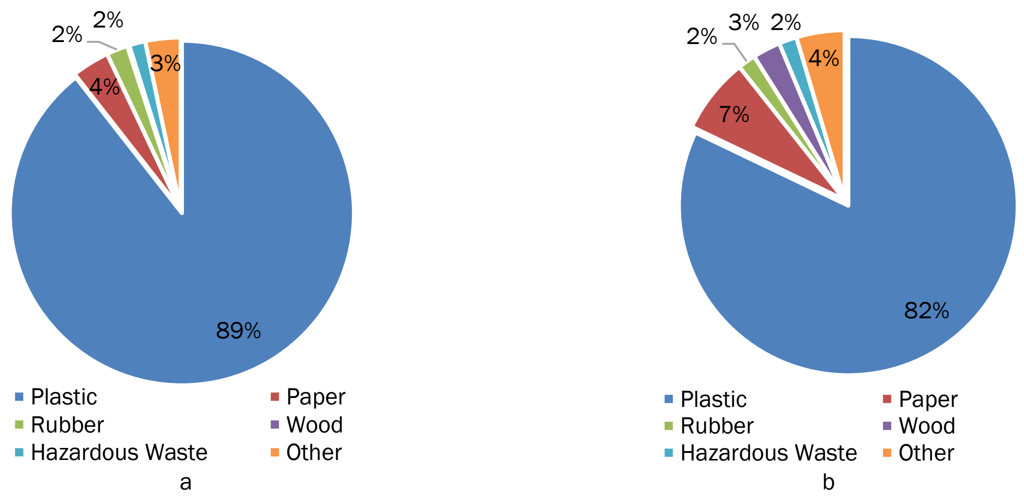

Figure 3. Composition of Marine Debris based on Materials, (A) Weekday; (B) Weekend

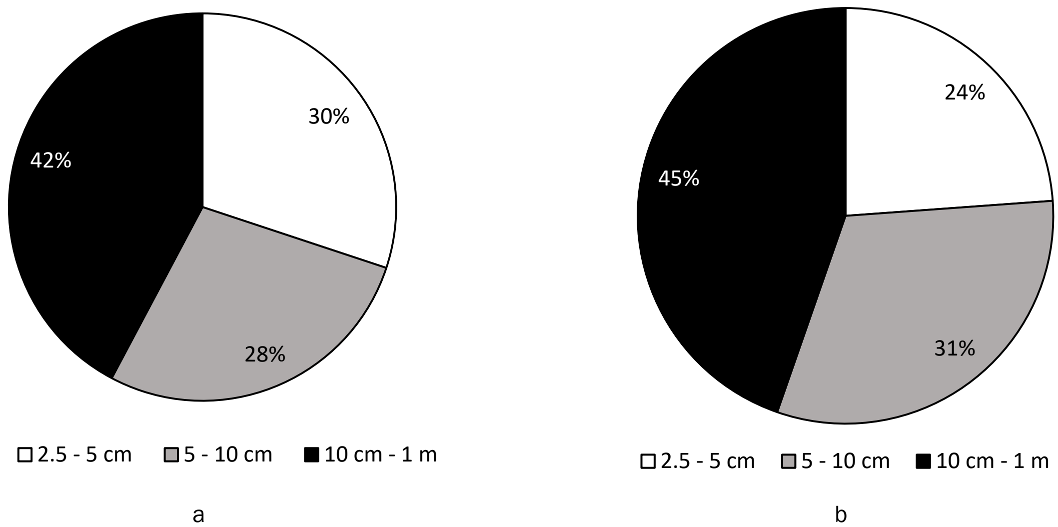

Figure 4. Composition of Marine Debris based on Size, (A) Weekday; (B) Weekend

zone is where visitors tend to concentrate their activities, leading to a higher likelihood of debris deposition. Furthermore, the backshore is less exposed to hydro-oceanographic factors, such as wave action and tidal currents, which can contribute to the breakdown and degradation of marine debris (Olivelli *et al.*, 2020). Consequently, larger debris items, often discarded by beachgoers, tend to accumulate in this area, as they are less susceptible to these natural degradation processes.

The size composition of marine debris across the four study sites (Figure 5) exhibited a similar distribution pattern, with the highest proportion of large-sized debris observed at Karanggongso Beach. This accumulation of large, undegraded waste is likely due to a combination of factors, including inadequate waste management practices and infrequent beach cleanups. Specifically, at Karanggongso Beach, the accumulation is exacerbated by the influx of debris carried by river estuary flows, which falls outside the designated coverage area of local waste management services. Increased human activities and development in the region have led to a rise in waste disposal into rivers, ultimately contributing to marine debris pollution (Amri *et al.*, 2023; Johan *et al.*, 2020; Yuniarti *et al.*, 2023). Therefore, addressing this issue requires a multi-faceted approach. In addition to regular beach clean-ups, interventions aimed at mitigating waste sources are crucial. This includes raising community awareness regarding responsible waste disposal and implementing improved waste management practices throughout the region (Kumar *et al.*, 2016; Assuyuti *et al.*, 2018; Johan *et al.*, 2020; Anna *et al.*, 2022; Amri *et al.*, 2023).

In contrast to the other study sites, Mutiara Beach exhibited a distinct pattern in the size distribution of marine debris. On weekdays, small macro debris was the most prevalent (47%), while on weekends, medium macro debris dominated (40%). This prevalence of smaller debris sizes at Mutiara Beach is likely due to the trapping and concealment of debris within vegetation and sediment, hindering its removal during beach clean-ups. Marine debris that reaches the backshore zone, particularly smaller items, can become entangled in vegetation, making it difficult to extract (Olivier *et al*., 2020; Egea *et al*., 2023). While regular cleaning efforts are effective in reducing the abundance of larger, more visible debris, smaller fragments tend to settle within coastal sediments, making them challenging to remove and contributing to their persistence in the environment (Silva *et al*., 2018; Waldschläger *et al*., 2020).

Abundance of marine debris

The average abundances of marine debris across four studied beaches during two different periods were 1.57±0.29 items.m^{-2} on weekdays and 1.93±0.38 items.m^{-2} on weekends (Figure 6). A comparison of marine debris abundance between weekdays and weekends revealed variations across the different study sites (Figure 7). On weekdays, the abundance ranged from 1.47 to 1.74 items.m^{-2}, while on weekends it ranged from 1.70 to 2.17 items.m^{-2}. Notably, the overall difference in abundance between weekdays and weekends was statistically significant (P<0.05). This finding indicates that despite the consistent input of debris from various sources, the influx of visitors on weekends contributes to a measurable increase in marine debris pollution at Prigi Bay. This observation aligns with findings from other studies conducted in coastal areas with significant tourism activity, which highlighting the influence of visitor behavior on coastal pollution levels (Hayati *et al*., 2020).

Meanwhile, in term of debris weight, the abundance was 4.69± 2.41 g.m^{-2} on weekdays and 8.86±4.33 g.m^{-2} on weekends (Figure 8). The abundance of marine debris exhibited a similar spatial pattern across the study sites for both weekdays and weekends (Figure 9). On weekdays, the abundance ranged from 2.37 to 8.34 g.m^{-2}, while on weekends it ranged from 4.54 to 11.82 g.m^{-2}. Importantly, the difference in weight abundance between weekdays and weekends was statistically significant (P<0.05). This result further emphasizes the impact of increased visitor activity on weekends, leading to a substantial rise in the overall weight of marine debris polluting the beaches of Prigi Bay.

Data analysis revealed significant differences (P<0.05) in both the amount and weight of marine debris between weekdays and weekends. This variation is attributed to the diversity of waste types observed, which is greater on weekends compared to weekdays, primarily due to increased human activity associated with tourism. Tourism activities generate a wider range of waste materials, including non-plastic debris such as wood and paper products

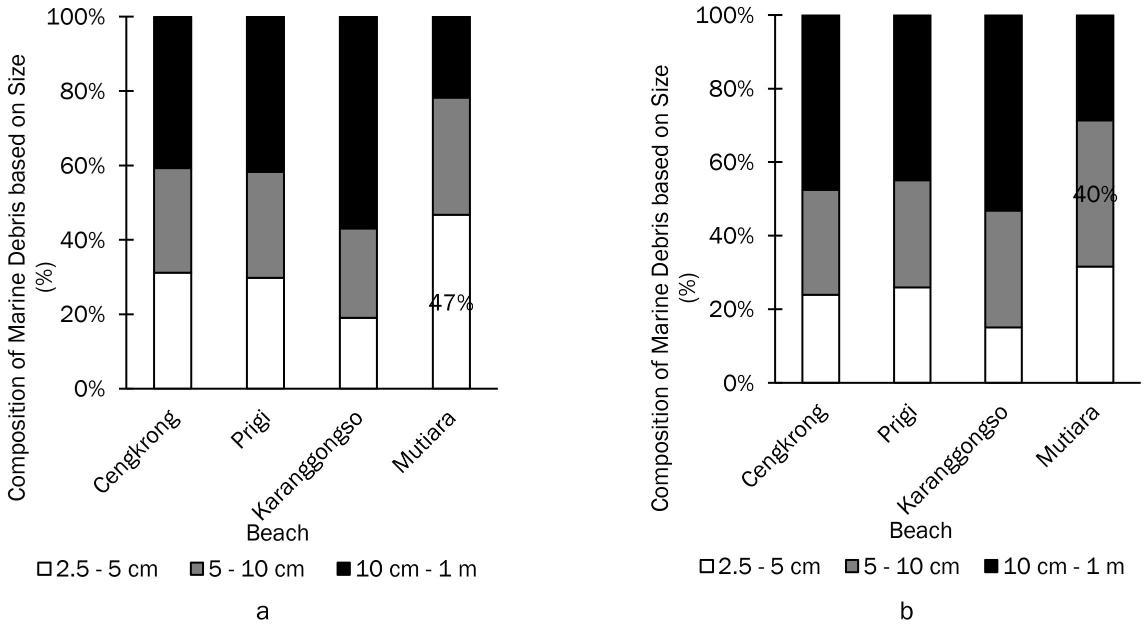

Figure 5. Size composition of marine debris at four stations, (A) Weekday; (B) Weekend

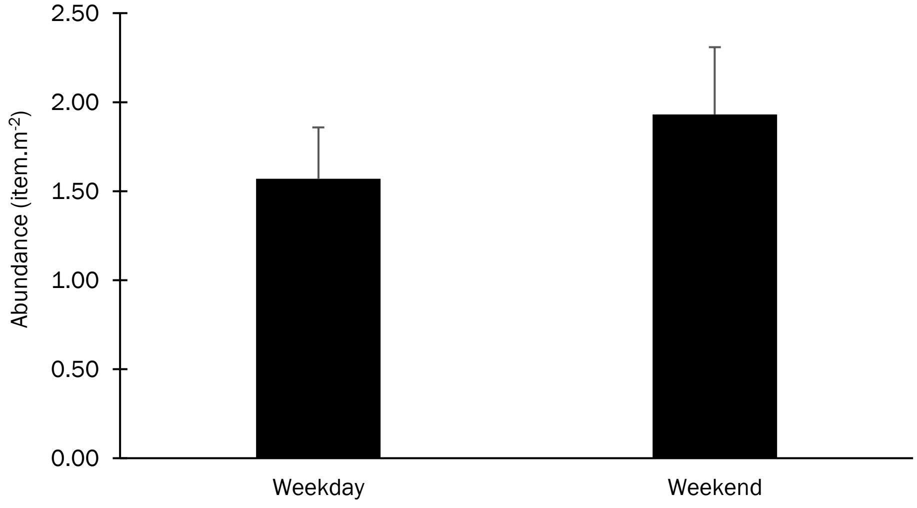

Figure 6. Abundance of marine debris (items.m^{-2}) during weekday and weekend

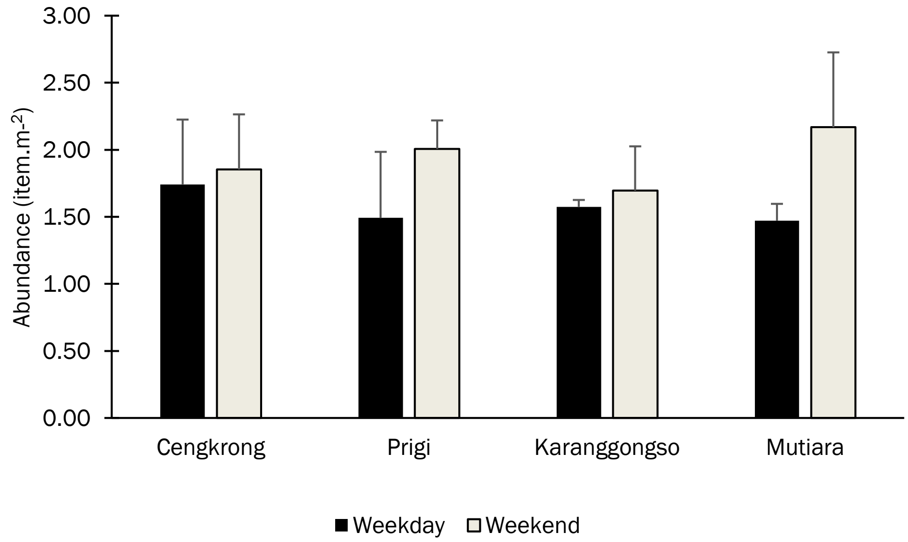

Figure 7. Abundance of marine debris (items.m^{-2}) during weekday and weekend across four sampling stations

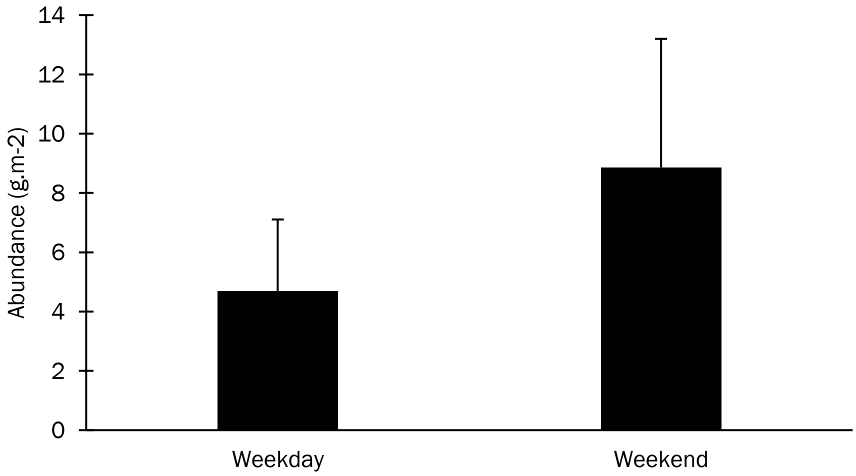

Figure 8. Abundance of marine debris (g.m^{-2}) during weekday and weekend

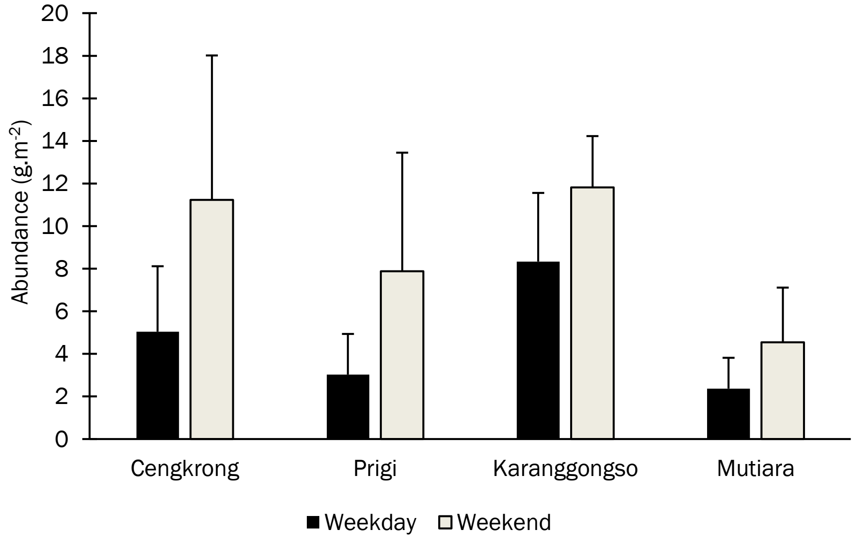

Figure 9. Abundance of marine debris (g.m^{-2}) during weekday and weekend across four sampling stations

(Kumar *et al*., 2016; Zaman *et al*., 2023). Examples of non-plastic waste identified in this study included tissue, cigarette packs, rice paper, food packaging, food sticks, and ice cream sticks. This finding is consistent with previous research indicating that tourism activities contribute to waste type variation, with wood and paper being the most prevalent non-plastic wastes (Zaman *et al*., 2023). These types of waste become more common on weekends, contrasting with the predominantly plastic waste observed on weekdays.

Furthermore, the variation in waste type influences the overall weight of debris between the two time periods. The increased diversity of waste on weekends, particularly the contribution of tourism-related food packaging (*e.g*., wood and paper), leads to a higher overall mass of debris. This is because such materials generally have a greater mass compared to the predominantly plastic waste generated on weekdays. Previous studies conducted on Bali's South Coast and Penyengat Island support this observation, indicating that while wood and paper waste may be less frequent than plastic waste, it tends to be denser and heavier (Ikhwan *et al*., 2021; Suteja *et al*., 2021). Conversely, the lower weight of waste observed on weekdays is attributed to the lighter nature of plastic debris. This finding is consistent with research indicating that plastic waste is generally lighter and more easily dispersed (Yuniarti *et al*., 2023).

The analysis of marine debris abundance, measured by both item count and weight, revealed distinct patterns between managed (Prigi and Mutiara) and unmanaged (Cengkrong and Karanggongso) beaches. While unmanaged beaches exhibited relatively stable debris levels across weekdays and weekends, managed beaches showed considerable variation, with increased debris observed on weekends coinciding with peak tourism activity. Several factors contribute to these observed variations, including location characteristics, cleaning frequency and effectiveness, anthropogenic impacts, and research methodologies (Bouzekry *et al*., 2022). The availability of amenities on managed beaches enhances their appeal to tourists (Budiyasa, 2017; Fitri and Sutedjo, 2019), leading to increased debris, particularly on weekends. Conversely, unmanaged beaches suffer from inadequate cleaning regimes and the influx of debris transported by estuaries, especially during rainy periods (Malau *et al*., 2018; Johan *et al*., 2020; Amri *et al*., 2023; Yuniarti *et al*., 2023), resulting in a heavier overall debris mass. The composition of debris also differed between the beach types. While macro-sized debris (10-100 cm) dominated at all locations, unmanaged beaches frequently accumulated larger items like diapers, logs, and fruit waste due to ineffective cleaning (Silva *et al*., 2018). This highlights the need for robust waste management systems, including regular cleaning, proper disposal infrastructure, and public awareness campaigns, to effectively address marine debris pollution and promote regional sustainability (Kumar *et al*., 2016; Assuyuti *et al*., 2018; Johan *et al*., 2020; Ashuri and Kustiasih, 2020; Anna *et al*., 2022; Amri *et al*., 2023).

This difference underscores the importance of effective management practices in mitigating the impact of visitor behavior on debris accumulation. To address this issue, a strategic plan can be implemented at both managed and unmanaged beaches. Key actions could include enhancing waste disposal infrastructure, increasing the frequency of beach clean-ups during peak tourist seasons, and launching comprehensive public education campaigns to raise awareness about the environmental impacts of littering. These efforts would aim to reduce debris accumulation by encouraging responsible visitors' behavior. Additionally, stricter enforcement of littering regulations and active community involvement in monitoring and reporting litter could further support long-term beach sustainability. Such practices, when applied consistently across both types of beaches, could reduce marine debris effectively in varying management contexts.

Clean Coast Index (CCI)

The Clean Coast Index (CCI) assessment for Prigi Bay Tourism Beach Area revealed that the cleanliness level falls into the "extremely dirty" category for both marine debris (35.01±6.66) and plastic waste (29.91±6.54) on both weekdays and weekends (Table 2). This classification indicates a high level of marine debris pollution across all study sites. Specifically, the average CCI values for marine debris were 31.40±5.76 on weekdays and 38.62± 7.56 on weekends, while for plastic waste, the values were 28.03±5.10 on weekdays and 31.79±7.98 on weekends. All these values exceed the threshold of 20, confirming the "extremely dirty" classification (Table 2). This assessment indicates that there is no significant difference in cleanliness levels between weekdays and weekends, likely due to the persistent high levels of anthropogenic activity throughout the week (Alkalay *et al*., 2007). The substantial anthropogenic activity in the Prigi Bay area, including the presence of a national-scale port with the largest Fish Auction Place (TPI) in East Java, contributes to the continuous input of litter and pollution into the marine environment (Fitri and Sutedjo, 2019; Yona *et al*., 2020; Sibaja-Cordero and Gómez-Ramírez, 2022). Consequently, the density of debris does not vary significantly between weekdays and weekends, as human activities maintain a consistently high level of pollution throughout the week (Zaman *et al*., 2023).

Although the average CCI values for all study sites fell into the "extremely dirty" category, variability was observed among the beaches. On weekdays, higher average CCI values were recorded at Cengkrong Beach (34.83±9.68) and Karanggongso Beach (31.50±1.01), while lower values were observed at Mutiara Beach (29.44±2.49) and Prigi Beach (29.83±9.86). Conversely, on weekends, higher CCI values were found at Prigi Beach (40.13± 4.25) and Mutiara Beach (43.36±11.16), and lower values at Karanggongso Beach (33.90 ± 6.61) and Cengkrong Beach (37.07±8.21). This pattern aligns with the two distinct groups of beaches identified earlier: Prigi and Mutiara Beaches, with higher tourism activity, exhibited increased CCI levels on weekends, likely due to the influx of visitors. In contrast, Cengkrong and Karanggongso Beaches, which experience less tourism activity, showed higher CCI levels on weekdays, reflecting the influence of other anthropogenic activities, such as fishing and local community waste disposal, which are likely more prevalent during the week.

Despite these variations, all beaches remained classified as "extremely dirty" according to CCI. This persistent high pollution level can be attributed to baseline debris accumulation, where plastics and other non-degradable waste persist over time (Kubowicz and Booth, 2017) regardless of short-term fluctuations. Additionally, limited waste removal and management efforts likely contribute to continuous debris buildup (Lebreton *et al*., 2019). Moreover, marine transport mechanisms, including tidal action, currents, and wind, may introduce debris from offshore or nearby areas, maintaining consistently

Table 2. CCI values in the Prigi Bay Tourism Beach Area

Day	Beach	CCI Marine Debris		CCI Plastic Waste	
		Mean	Category	Mean	Category
Weekday	Cengkrong	34.83±9.68	Extremely Dirty	29.36±7.63	Extremely Dirty
	Prigi	29.83±9.86	Extremely Dirty	25.67±8.95	Extremely Dirty
	Karanggongso	31.50±1.01	Extremely Dirty	29.40±1.31	Extremely Dirty
	Mutiara	29.44±2.49	Extremely Dirty	27.68±2.51	Extremely Dirty
	Average	31.40±5.76	Extremely Dirty	28.03±5.10	Extremely Dirty
Weekend	Cengkrong	37.07±8.21	Extremely Dirty	27.57±9.33	Extremely Dirty
	Prigi	40.13±4.25	Extremely Dirty	32.07±7.15	Extremely Dirty
	Karanggongso	33.90±6.61	Extremely Dirty	28.53±5.09	Extremely Dirty
	Mutiara	43.36±11.16	Extremely Dirty	38.99±10.35	Extremely Dirty
	Average	38.62±7.56	Extremely Dirty	31.79±7.98	Extremely Dirty
Average Both Day		35.01±6.66	Extremely Dirty	29.91±6.54	Extremely Dirty

high contamination levels (Handyman *et al*., 2018). Since CCI is a cumulative index, minor fluctuations in debris input between weekdays and weekends are insufficient to shift the pollution classification. These findings highlight the necessity of long-term monitoring and effective waste management strategies that account for both tourism-driven and local anthropogenic waste sources to mitigate sustained marine debris accumulation.

To accurately measure marine debris pollution in Prigi Bay, this study conducted a comparative analysis of debris abundance and CCI values against those documented in prior studies of the coastal regions (Table 3). The CCI values for marine debris in Prigi Bay were comparable to those reported for Karang Ria and Tidung Beach in Indonesia, the Santa Catarina Coast in Brazil, the Caribbean Coast in Colombia, the North Coast of Istanbul in Turkey, Macalajar Bay in the Philippines, and Ambon Bay in Indonesia (Rangel-Buitrago *et al*., 2019a; 2019b; Esquinas *et al*., 2020; Hayati *et al*., 2020; Manullang *et al*., 2021; Akarsu *et al*., 2022; Poluan *et al*., 2023). However, the Prigi Bay values were higher than those reported for the South Coast of Bali in Indonesia, Punta Arenas in Chile, the Niteroi Coast in Brazil, and Quangdou in China (Suteja *et al*., 2021; Pervez and Lai, 2022; Silva *et al*., 2022; Salinas *et al*., 2024). The CCI value for plastics at the study site was similar to that reported for Coastal Santa Catarina, Brazil, but higher than that reported for Chile (Rangel-Buitrago *et al*., 2019b; Salinas *et al*., 2024). This comparison provides context for the current study and highlights the widespread challenge of marine debris pollution in coastal environments globally.

This study advances marine debris assessment methodologies by refining the Clean Coast Index (CCI) application and optimizing sampling techniques for greater reliability and representativeness. Unlike previous studies, CCI was systematically applied across multiple beaches with varying tourism intensities, providing a more detailed evaluation of human-driven debris accumulation. The study also employed a standardized 5×5 m quadrat transect method at 20 m intervals, ensuring consistent spatial representation, while sampling during low tide minimized tidal influence, improving comparability across sites. Beyond methodological advancements, persistently high CCI scores in Prigi Bay have significant long-term ecological and socio-economic implications, including threats to coastal biodiversity, habitat degradation, and contamination risks to fisheries. Additionally, excessive marine debris could deter tourism, impacting local livelihoods dependent on coastal resources. The continued degradation of Prigi Bay may lead to cumulative economic losses for fishing communities and tourism operators if not addressed. Long-term monitoring, improved waste management, and sustainable tourism practices are essential to mitigate these risks. Future studies should incorporate seasonal variations, source-tracking analyses, and predictive modeling to enhance marine debris management strategies further.

Implications for sustainable coastal tourism

The persistent classification of Prigi Bay beaches as extremely dirty, highlights a major challenge for sustainable coastal tourism. Clean

Table 3. Comparison of abundance and CCI at the study site with values reported in other studies

Research Location	Abundance (items.m^{-2})	CCI Marine Debris	CCI Platic Waste	Classification	Dominant Waste	Reference
Cengkrong Beach, Indonesia	1.80±0.45	35.95±8.95	28.47±8.48	Extremely Dirty	Plastic (79%)	This study
Prigi Beach, Indonesia	1.75±0.35	34.98±7.05	28.87±8.05	Extremely Dirty	Plastic (83%)	This study
Karanggongso Beach, Indonesia	1.64±0.19	32.70±3.81	28.97±3.20	Extremely Dirty	Plastic (89%)	This study
Mutiara Beach, Indonesia	1.82±0.34	36.40±6.83	33.33±6.43	Extremely Dirty	Plastic (92%)	This Study
Ambon Strait, Indonesia	18.87	377.4	-	Extremely Dirty	Plastic (87%)	(Manullang *et al*., 2021)
South Coast of Bali, Indonesia	0.356	7.12±7.32	-	Moderately Clean	Plastic (87%)	(Suteja *et al*., 2021)
Karang Ria Beach, Indonesia	1.98	39.6	-	Extremely Dirty	Plastic (84%)	(Poluan *et al*., 2023)
Tidung Beach, Indonesia	1.83	36.6	-	Extremely Dirty	Plastic (84%)	(Hayati *et al*., 2020)
Punta arenas, Chile	0.49±0.37	9.8±7.41	2.9	Moderately Clean	Plastic and glass (63%)	(Salinas *et al*., 2024)
Santa Cantarina Coast, Brazil	2.78	55.6±71.1	36.7 ± 64.5	Extremely Dirty	Plastic (69%)	(Marin *et al*., 2019)
Karibia Beach, Columbia	5.11	102.2	-	Extremely Dirty	Plastic (88%)	(Rangel-Buitrago *et al*., 2019a)
Macalajar Strait, Philippines	4.25	85	-	Extremely Dirty	Plastic	(Esquinas *et al*., 2020)
Qindao Beach, China	0.08±0.02	1.6	-	Very Clean	Plastic	(Pervez and Lai, 2022)

beaches are essential not only for preserving marine ecosystems but also for maintaining the attractiveness of tourism destinations (Otto, 2025) Without effective waste management, the continuous presence of debris could reduce tourist satisfaction and potentially diminish economic benefits derived from coastal tourism. Integrating sustainable tourism practices, such as eco-friendly waste facilities, community-based clean-up programs, and visitor education campaigns, would help mitigate debris accumulation. Moreover, incorporating sustainability principles into coastal tourism planning ensures that recreational use of beaches can coexist with long-term environmental conservation and socio-economic resilience.

Conclusion

This study examined marine debris at four recreational beaches in Prigi Bay, comparing weekdays and weekends. The results showed that the type and size of debris did not differ significantly between weekdays and weekends, with large macroplastics being the most dominant. However, the amount and weight of debris were significantly higher on weekends due to increased tourism-related waste, particularly wood and paper products. The Clean Coast Index (CCI) classified all beaches as "extremely dirty" regardless of the day, highlighting the urgent need for comprehensive waste management strategies addressing both local and tourism-related pollution sources. While this study provides valuable insights, we acknowledge that marine debris distribution can vary across spatial and temporal scales. As our research was conducted over a relatively short period, future studies should explore a broader temporal scale, including seasonal variations, and expand the geographical scope to capture more comprehensive patterns of marine debris accumulation and movement. Additionally, further research should investigate the sources and pathways of marine debris to better understand the key contributors to pollution in the region. Examining the potential impacts of marine debris, particularly plastics, on marine ecosystems and biodiversity would provide a more holistic understanding of the issue and support the development of targeted mitigation strategies. Importantly, the findings emphasize that maintaining sustainable coastal tourism requires linking effective waste management with tourisms development to ensure long-term ecological and socio-economic resilience.

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