

Effects of seasonal variation on the characteristics of stranded marine debris within Rambut Island Wildlife Reserve, Indonesia

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Abstract

Monitoring and assessing the items stranded on shorelines is a crucial step in addressing the threat posed by marine debris to our ocean. The objective of this study is to examine the occurrence and categorize marine debris that accumulates on the beach and mangrove area of Pulau Rambut Wildlife Reserve from the transitional season 2 to the rainy season. The abundance of marine debris is significant in transitional season 2. There is no significant difference between different seasons. The dominant form of debris among all macrodebris categories during transitional season 2 was plastic, accounting for 46.38% of the total. Single-use plastics like styrofoam, shoes, sandals, gloves, plastic wrap, and plastic sachets were found to be the most common types of large-scale plastic debris, comprising 60% of total macroplastic debris. The debris found on Rambut Island is believed to originate from debris carried by rivers that flow into Jakarta Bay. The presence of seasonal winds, currents, waves, and tides further contribute to the accumulation of debris in this area.

Keywords: Seasonal variation, Marine debris, Rambut Island

INTRODUCTION

Marine debris refers to any solid material of human origin that is discarded or abandoned in marine and coastal environments (Jeftic *et al.*, 2009). This includes all materials that are discharged into the ocean as a result of activities in coastal environments, as well as waste generated from land that is carried indirectly to the ocean through rivers (NOAA, 2018). Marine debris is a significant threat to the environment and is a topic of frequent discussion in regards to pollution (Williamson *et al.*, 2016). Extensive research has been carried out on marine debris. A significant proportion, 60-80%, of marine debris is plastic waste (Derraik, 2002).

Plastic is a macromolecule that results from the polymerization process. This process involves the merging of multiple simple molecules (monomers) through a chemical reaction to form larger molecules (macromolecules or polymers) (PlasticsEurope, 2013). Plastics were initially developed in the 1800s and were made from organic polymers and biological materials. The production and utilization of plastics experienced a swift increase during the 1950s. Birmingham-born Alexander Parkes introduced the first synthetic plastic, Parkesine, in 1856. Gradually, plastics became involved in almost every facet of everyday life. In not even a century, plastic has emerged as a relatively new material in contrast to more conventional materials like wood, metal, stone, and glass. Plastics are utilized across various domains of society, such as packaging, construction, transportation, medical, sports, recreation, electronics, agriculture, and currency (Merkl and Stuchtey 2015).

Incidents of plastic waste leaking into the marine environment have been widely reported. Technical term abbreviations, if used, need to be explained. The 2017 report, "New Plastics Economy- Rethinking the Future of Plastics," concluded that the improper management of plastic waste

impacts the entry of plastic waste into the marine environment. About 40% of plastic waste is disposed of in landfills, and 32% leaks from poorly managed collection systems. Another report states that 9% of waste is recycled, 12% is burned, and the remaining 79% is stored in landfills or released directly into the environment (Geyer *et al.*, 2017). Indonesia is among the countries that significantly contribute to marine debris in the world's oceans (Jambeck *et al.*, 2015). The substantial accumulation of marine debris in Indonesia results from several human activities and high coastal population density (Purba *et al.*, 2019). Among the many areas that contribute to marine debris in Indonesia, Jakarta Bay is a particularly concerning region (Faizal *et al.*, 2022). Jakarta's rivers are a significant source of marine debris in the world's oceans (Van Calcar and Van Emmerik, 2019). Pollution in Jakarta Bay can affect the surrounding area, particularly the economic sector, which experiences a decline in income from beach tourism. A significant factor contributing to this negative impact is the lack of tourist interest in a recreational environment that is no longer attractive due to marine debris (Hardesty *et al.*, 2015).

The distribution of marine debris along coastlines is primarily impacted by the flow of currents. Currents are a prominent aspect influencing the drift of marine debris over long distances (NOAA, 2016). The direction of surface currents in Indonesian waters is greatly impacted by the monsoon wind system that changes direction twice yearly, a result of high- and low-pressure variations between the Asian and Australian continents. Wind movements in both seasons are characterized by winds moving from Australia to Asia in the east monsoon and the opposite in the west monsoon (Jalil, 2013).

Several studies have analyzed the impacts that occur in various areas around Jakarta Bay, including Rambut Island, which is a crucial breeding and resting habitat for diverse seabird species (Ramsar, 2011). This region has undergone various studies concerning marine debris, including research by Ivonie (2021), which demonstrated that the quantity of marine debris amassed in the mangrove ecosystem could impact its growth. The findings of this study are a crucial factor in justifying its purpose. Presence and buildup of marine debris in mangrove areas contribute to the degradation of the ecosystem, hindering natural regeneration by occupying soil space and interfering with the formation and growth of mangrove propagules and seedlings.

Research on monitoring marine debris in marine protected areas is inadequate, particularly in Indonesia. The study by Ivonie (2021) had a short duration, this research examines the trend of substantial marine debris accumulation periodically during the transitional season 2 (September-October) and the west season (November-December). This study aims to provide objective data on the characteristics and distribution of marine debris in two seasons on Rambut Island. The results of the study have significant implications for policymakers, stakeholders, and local communities in developing viable solutions to reduce marine debris and promote environmental sustainability. The information gathered will serve as a basis for formulating activities and initiatives necessary for implementing an effective waste management strategy to preserve Rambut Island's beautiful environment and sustainable resources.

MATERIAL AND METHODS

Rambut Island is a part of the Untung Jawa Island urban village, located in the South Seribu Islands Sub-District of the Seribu Islands Administrative Regency. With an area estimated at around 90 hectares, this island features a brackish coral environment that supports diverse mangrove and coastal forest vegetation. Rambut Island showcases three different forest ecosystems: lowland forests, coastal forests, and mangrove forests (Firdausy *et al.*, 2021). The plants and trees in this region provide habitats for a variety of water birds, making it known as a sanctuary for seabirds (BKSDA, 2015). Rambut Island is an important refuge for the Brahminy kite (*Haliastur indus*), which is considered the symbol of Jakarta. Additionally, the island plays a vital role as a stopover point along the migratory route between East Asia and Australia, attracting numerous water birds during their journey from the Northern Hemisphere to Australia between October and December (Ramsar, 2011). The

coastal forest ecosystem of Rambut Island is known for its sandy beaches accompanied by coastal vegetation like katang-katang (*Ipomoea pes-caprae*), sea cypress (*Casuarina equisetifolia*), and ketapang (*Terminalia catappa*). The mangrove station is close to a water channel located in the mangrove ecosystem leading to the southwest of Rambut Island. Rambut Island mangrove ecosystem is made up of nine types of mangrove trees, including: *Rhizophora mucronata*, *Rhizophora stylosa*, *Rhizophora apiculata*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, *Excoecaria agallocha*, *Xylocarpus granatum*, *Avicennia officinalis*, and *Phempis acidula* (Kusmana and Azizah, 2022). *Rhizophora mucronata* and *Ceriops tagal* are the dominant species within this ecosystem.

The study was carried out during the period of September to December 2021, specifically focusing on transitional season 2 and the rainy season. Initial field surveys were conducted to identify areas with accumulated debris, from which several sampling stations were selected. The selection of these station points took into consideration factors such as the abundance of marine debris piles, characteristics of the local ecosystem, and tourist activity patterns. The designated stations included various coastal and mangrove areas, as well as a beach station and a mangrove station (Figure 1). It is worth noting that the beach station is located in the southeastern region along the coast.

The sampling methodology and waste categorization were adopted from the guidelines provided by NOAA (Lippiatt *et al.*, 2013) and UNEP/IOC (Cheshire *et al.*, 2009). In coastal areas, marine debris sampling was conducted using quadrant transects measuring 30 meters in length and 8 meters in width. Specifically, these transects extended to a distance of 4 meters towards both the upper supratidal zone and the middle supratidal zone (Figure 2A). In the mangrove area, a modified method was used based on Martin *et al.*, (2019), with transect measurements of 5 meters in length and width. Species identification for mangrove stations involved visual analysis of leaves, flowers, propagules, bark, and fruit for all mangroves species present along each transect line (Kitamura *et al.*, 1997; Primavera *et al.*, 2004; Giesen *et al.*, 2006). Marine debris items were categorized into various types including plastic materials as well as rubber, metal, wood, glass, and cloth. Moreover, we have divided our samples into specific sub-categories based on previous studies.

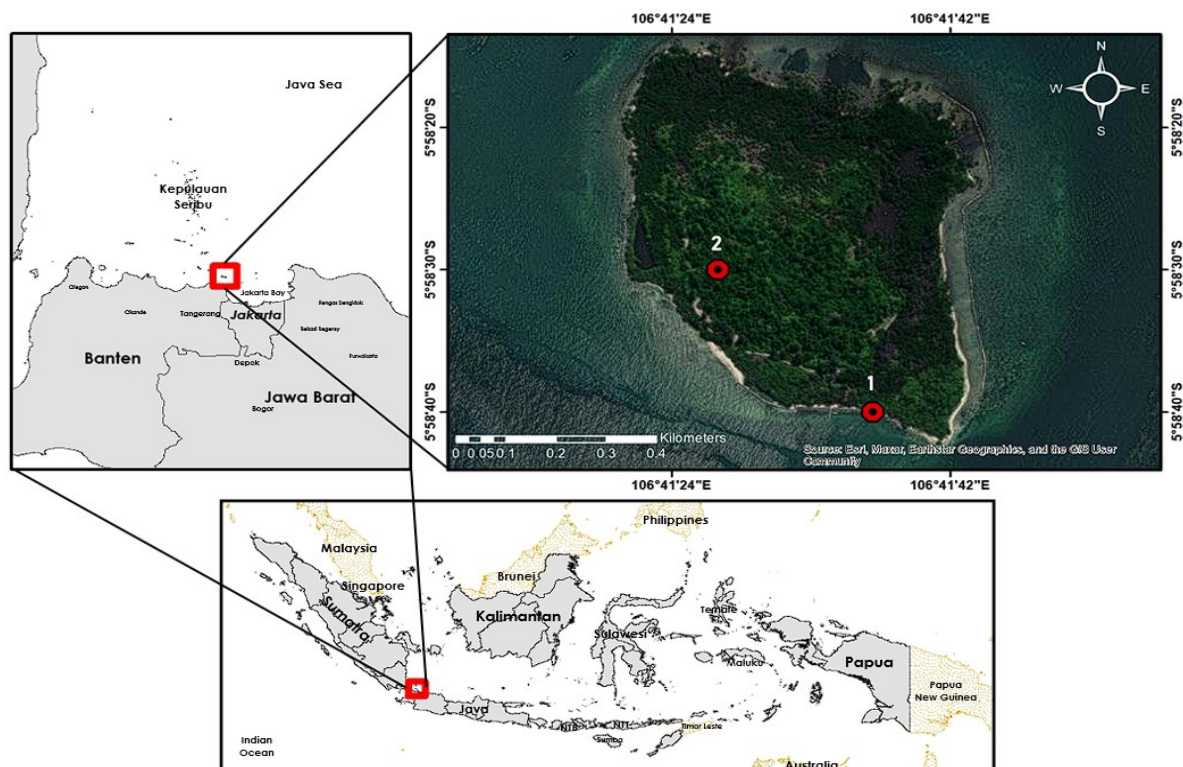


Figure 1. Map of research locations and sampling points on Rambut Island, beach station ($5^{\circ}58'39''S$ $106^{\circ}41'36''E$ and mangrove station ($5^{\circ}58'28''S$ $106^{\circ}41'26''E$).

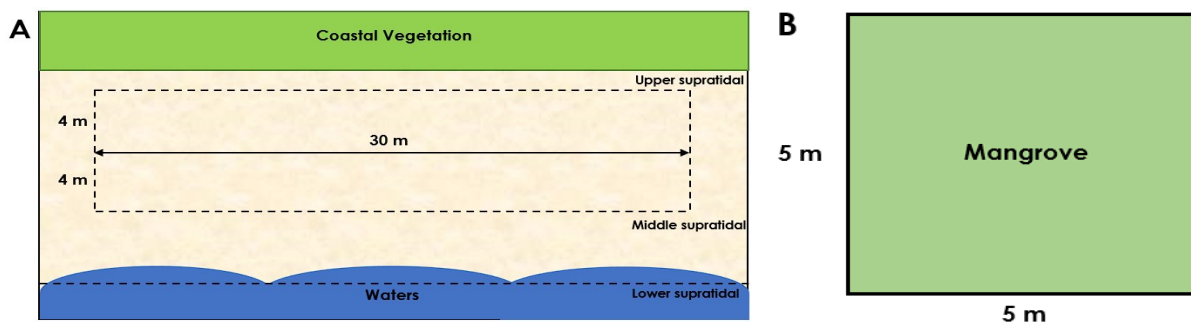


Figure 2. Transect for marine debris collection areas at beach station (A) and mangrove station (B)

All the collected samples of marine debris were thoroughly cleaned and dried prior to being counted for both abundance and weight. Scales with an accuracy of 0.1g were utilized during this process. In order to determine the density of the marine debris, we employed the following equation:

$$D = \frac{n}{\omega \times l}$$

D represents the density of marine debris (items/weight/m²), n is the amount/weight (kg) of marine debris observed, ω denotes the width of the transect in meters, and l denotes the length of the transect (m).

The analysis employed statistical tests such as the Kruskal-Wallis and Mann-Whitney tests to identify any differences in marine debris between the various sampling transects. Data analyses were performed using PAST version 4.03 software.

RESULTS AND DISCUSSION

During the monitoring period on Rambut Island, a total of 3491 marine debris items were discovered, with an average density of 1.82 ± 0.76 items/m². In addition, the collected weight was 66,827 grams with an average density of 34.81 ± 10.34 gr/m². At the beach station, a total of 1551 debris items were observed, with an average density of 1.62 ± 0.98 items/m² and weighing in at a total of 27,918 grams (average density: 29.08 ± 7.17 gr/m²). In comparison to the other research stations, the mangrove station produced more significant results in terms of abundance and weight of marine debris found (Figure 3A). Specifically, at the mangrove station, a total of 1940 waste items were observed with an average abundance rate of 2.02 ± 0.54 items/m². The combined weight of these items was 38,909 grams with an average abundance rate of 40.53 ± 10.53 gr/m². Despite conducting a paired post hoc test using the Mann-Whitney test (p > 0.05), no significant differences between the research stations were detected.

The total amount and weight of marine debris collected during the sampling period showed a fluctuating pattern (Figure 3B). The month with the highest abundance of marine debris was October, with an average of 2.70 ± 0.38 items/m², while the lowest was in December with an average of 1.19 ± 0.06 items/m². The quantity of marine debris experiences a significant rise in November (43.76 ± 13.15 gr/m²) and reaches a minimum point in October (27.92 ± 0.88 gr/m²). Upon analyzing the data, no substantial variances were found in the abundance or weight of stranded marine debris collected across the research stations during the sampling period (post hoc test and Mann-Whitney test, p > 0.05).

After examining the quantity of debris collected during each season, it was observed that the highest abundance of marine debris occurred during transitional season 2 (Figure 3C), at a rate of 2.08 ± 0.97 items/m². Conversely, the lowest amount was recorded during the rainy season, with an

average of 1.56 ± 0.50 items/m². Additionally, heavy abundance reached its peak in the rainy season at a mean value of 40.65 ± 8.83 gr/m² and showed its lowest level in transitional season 2 at an average measurement of 28.96 ± 8.97 gr/m². There were no significant variations detected in terms number or weight between different seasons as confirmed by post hoc and Mann-Whitney tests ($p > 0.05$). This study offers valuable information on the accumulation of marine debris during different seasons, specifically the transitional and rainy seasons. However, there is a need to accurately determine the quantity of marine debris in both the first transition season and dry seasons. To address this concern, conducting studies throughout all four seasons will provide a comprehensive analysis of marine debris abundance across these periods, enabling comparisons between them. The total amount of marine debris in the Rambut Island beach ecosystem far exceeded that documented in Lady's mile beach (Republic of Cyprus) and San Cristobal Island, Galapagos Islands, (Ecuador). However, debris in mangrove ecosystems did not surpass that in Tarout Island (Saudi Arabia), while that along the Entire Indian Coast (India) did not exceed Rambut Island.

Table 1. Comparison of marine debris on Rambut Island with other areas

Studi Location Beach	Study Year	Abundance (Item/m ²)	Waste Type Domination (%)	Reference
Rambut Island, Indonesia	2021	2.02 ± 0.54	Styrofoam (37%)	This study
Lady's mile beach, Republic of Cyprus	2021	0.15 ± 0.03	Bottles and caps plastic (23%)	Orthodoxou <i>et al.</i> , 2022
San Cristobal Island, Galapagos Islands, Ecuador	2018	0.27 ± 0.12	Plastic fracture (49%)	Jones <i>et al.</i> , 2021
Mangrove				
Rambut Island, Indonesia	2021	1.62 ± 0.98	Styrofoam (63%)	This study
Tarout Island, Saudi Arabia	2017	3.0 ± 2.0	Plastic strap (29.4%)	Martin <i>et al.</i> , 2019
Entire Indian Coast, India	2021	0.3 ± 0.4	Wrapping food (19%)	Mishra <i>et al.</i> , 2023

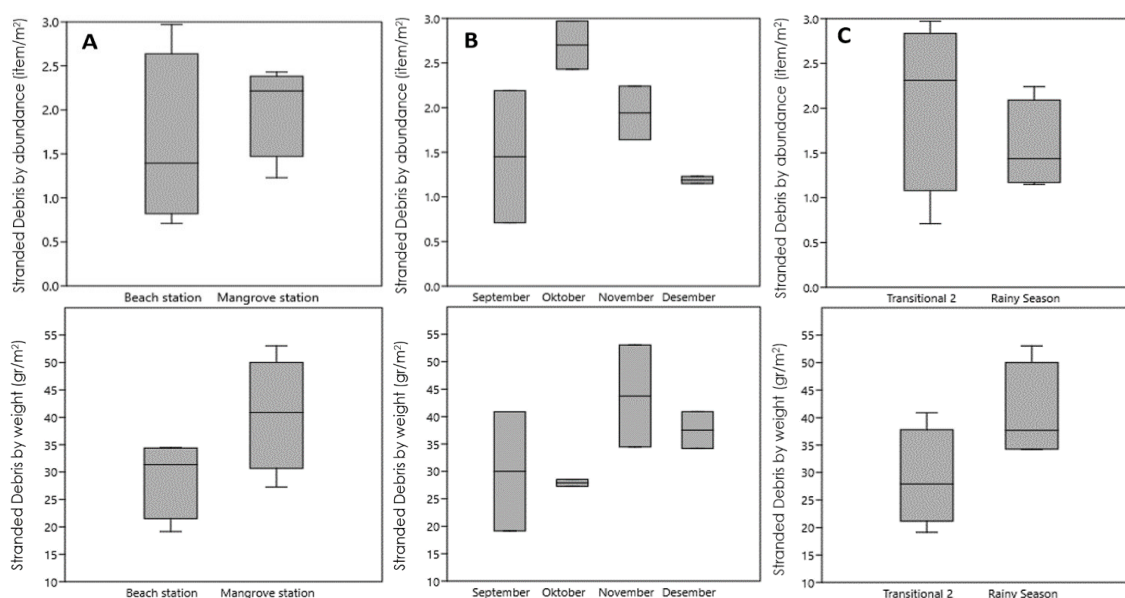


Figure 3. Marine debris based on abundance and weight at each location (A), month time period (B), and all seasons (C)

The high abundance of marine debris on Rambut Island can be attributed to several factors. Circulation patterns, changes in current direction, and various seasonal winds during the sampling period can affect the density of marine debris obtained (Mansui *et al.*, 2015; Maharani *et al.*, 2018). During the sampling in transitional season 2, the current moved from east to west. It is hypothesized that the current carries marine debris from the east of Rambut Island, originating from Jakarta Bay, islands in the Thousand Islands, and Java Island. Conversely, during the rainy season, the current moves from west to east. It is believed that the currents carry a lot of marine debris from the west of Rambut Island, which is thought to have come from the Sunda Strait, Lampung region, Banten Bay and surrounding areas. In addition, the relatively open nature of Rambut Island may also allow the input of accumulated garbage from various places. The rivers in Jakarta Bay also play a very important role in the many contributions of marine debris accumulated around the Jakarta Bay area, including Rambut Island. According to Iskandar (2022), the Citarum and Cisadane rivers are the most important sources of marine debris, with these rivers discharging more than times the number of debris directly into Jakarta Bay.

Differences in marine debris trends across research stations may be due to differences in ecosystem characteristics and topography (Kar *et al.*, 2021). The substantial quantity of marine debris present in the mangrove station is inseparable from the role that mangroves play as a barrier and absorbent for marine debris, preventing its spread into the marine environment (Martin *et al.*, 2019). When sea levels rise or during storms, high waters surpass the low coastlines and carry marine debris into the mangrove area. Subsequently, when conditions calm, the debris remains trapped within the mangroves, leading to an accumulation of debris. The analysis conducted at the mangrove station revealed *Rhizophora mucronata* and *Avicennia officinalis* as the primary species along the transect. It remains possible that varying root structures found among different types of mangroves can impact the density of marine debris that becomes trapped within the associated ecosystem (Luo *et al.*, 2021). This study is supported by research carried out on Penang Island, Malaysia (Yin *et al.*, 2020). This study highlights disparities in the number of marine debris discovered in two varieties of mangroves, *Rhizophora mucronata* and *Avicennia sp.* It is believed that the diverse root structures of these mangroves are a contributing factor to debris accumulation. However, additional factors, such as species density (Luo *et al.*, 2021), also affect debris density in the mangrove ecosystem.

The tidal phenomenon is believed to impact the quantity of waste present at the beach station. During high tide, marine debris is deposited on shore, while during low tide, some debris is carried back into the ocean. This factor aligns with the function of tides, serving as the primary force that dictates the mobility patterns of marine debris (Ramos *et al.*, 2011). Differences in tidal height within the intertidal zone are considered a potential factor in the accumulation of marine debris carried by currents. In addition, variations in marine debris density among stations can be attributed to the cleaning initiatives implemented in coastal areas of Rambut Island. This cleanup effort was conducted by DKI Environmental Services with a cleaning frequency of once every two months, and by Jakarta BKSDA twice a week. These debris management activities can alter the debris density collected during sampling at all stations. Differences in the quantity and weight of marine debris between Rambut Island and the other areas can be attributed to several factors, such as sampling location, technique, and frequency, cleaning activities in each location, as well as natural and human factors (Ryan *et al.*, 2014; Portman and Brennan, 2017; Chen *et al.*, 2019; Özden *et al.*, 2021).

The study findings reveal that plastic waste comprises the majority of marine debris collected (Figure 4C). The average amount of plastic debris detected was 2.91 ± 1.20 items/m² by weight 32.54 ± 8.19 gr/m². Besides plastic debris, there are other marine debris categories with an average abundance greater than 0.05 items/m², such as the rubber and glass categories. The rubber category had an average abundance of 0.60 ± 0.19 items/m² in weight of 24.05 ± 7.55 gr/m², while the glass category had an average abundance of 0.07 ± 0.03 items/m² in weight of 7.15 ± 3.42 gr/m².

Post hoc and Mann-Whitney tests revealed significant differences in average abundance and weight among all categories of marine debris ($p < 0.05$). When comparing the two seasons depicted

in Figures A and B, it becomes apparent that the abundance of plastic debris categories is more dominant during second transition season with 3.31 ± 1.58 items/m² (Figure 4A). Conversely, the weight category of marine debris is more dominant during the monsoon season with 37.43 ± 7.79 gr/m² (Figure 4B). Upon analyzing the composition of plastic debris, it is then revealed that Styrofoam is the most prevalent type of debris, accounting for 63% at the mangrove station and 37% at the beach station (Table 2). The prevalence of the marine debris category in this study was similarly observed in the Lofoten Archipelago, Norway (Solbakken *et al.*, 2022) and Mumbai, India (De *et al.*, 2022).

Table 2. 8 categories of marine debris that are most commonly found at all stations

Research Station	Top 8 Categories of Marine Debris Found			
	1	2	3	4
Beach Station	Styrofoam 37 %	Crackle plastic wrap, sachet plastic wrap 17 %	Plastic cups 16 %	Straws, cotton buds and the like 12 %
Mangrove Station	Styrofoam 63 %	Shoes, used sandals, gloves, bits and pieces 25 %	Plastic bottles and plastic caps 4 %	Rubber bands, pieces of rubber 2 %
	5	6	7	8
Beach Station	Plastic bottles and plastic caps 8 %	Shoes, used sandals, gloves, bits and pieces 6 %	Drug packs (sachets/medicine bottles) 2%	Plastic break 2%
Mangrove Station	Straws, cotton buds and the like 2%	Shoes, used sandals, gloves, bits and pieces 2%	Packaging for cosmetics, toiletries, etc 1 %	Plastic break 1%

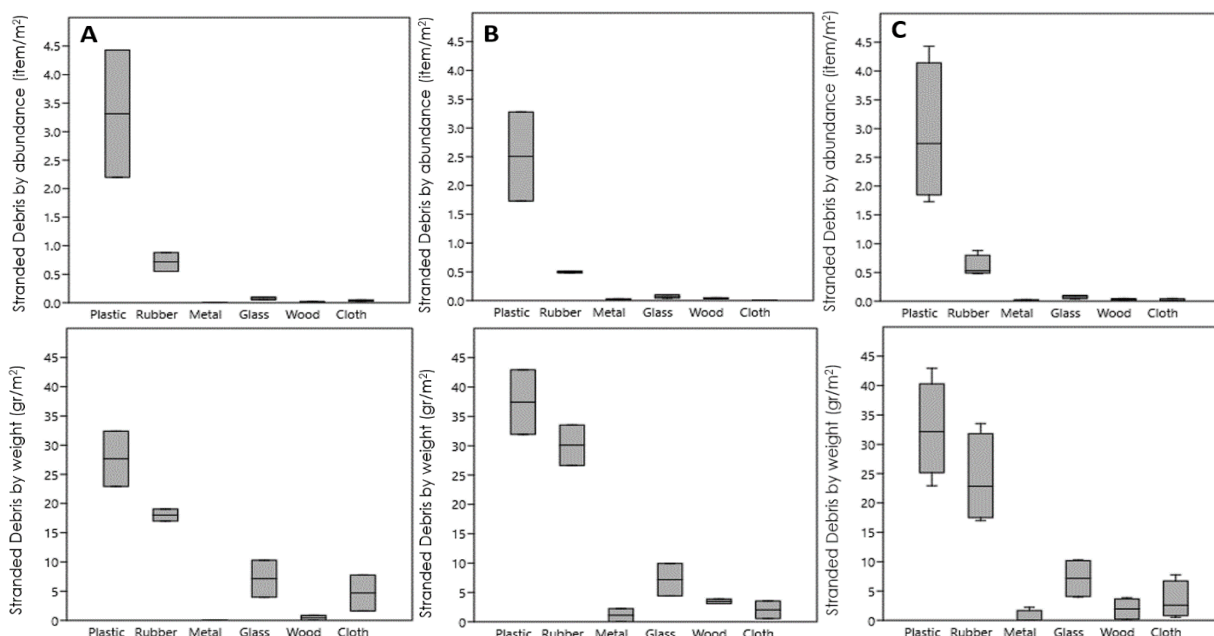


Figure 4. Marine debris categories based on abundance and weight in second transition season (A), moonson (B) and all seasons combined (C)

The significant number of plastic debris discovered cannot be disconnected from the tourist activities in the Seribu Islands zone. These activities have an effect on the neighboring region, which includes Rambut Island. Various previous studies have shown that plastic debris is the dominant category of debris in coastal areas (Zhou *et al.*, 2011). The prevalence of plastic debris results from its lower density compared to other types of debris, making its transportation to various areas simpler, including mangrove and coastal ecosystems (Ryan *et al.*, 2009). The abundance of plastic debris is a direct consequence of its excessive use in everyday activities. Plastic is the primary material for various products due to its lightweight, durability, affordability and low cost (Derraik, 2002).

Given the sanctuary status of the area, it is critical to consider the numerous ecosystems and biota that inhabit it. Effective management of marine debris would have a significant impact on the region. A detailed plan is required to mitigate the impacts within the Rambut Island wildlife reserve area. Regular marine debris cleanup activities carried out by the local government can significantly decrease the discharge of stranded marine debris in the reserve. Nevertheless, this effort could be further enhanced by conducting clean-up operations in the mangrove ecosystem area of the Rambut Island wildlife reserve. Handling the problem of plastic debris requires collaborative efforts across all relevant parties, including the community, policymakers, and scientists. A viable solution involves educating the community on reducing dependency on plastic materials, which can be accomplished through training programs. Additionally, tightening regulations and increasing awareness about the importance of cleanliness can greatly decrease negative impacts on the surrounding ecosystem. Not only is an increase in recycling capacity with adequate facilities necessary for managing plastic debris, but another suggestion is to transform plastic debris into various materials that can be used for different purposes with plastic being the primary material.

CONCLUSION

Research conducted between September-December 2021 at all research stations established that the mangrove stations contained the highest abundance of marine debris. It is also noteworthy that October shows a substantial total abundance of debris compared to other months, while November exhibits a dominant weight of debris abundance. Marine debris collected during the sampling period demonstrated that debris abundance was dominant during second transition season, while debris weight was dominant during the monsoon season. It was concluded that plastic debris was the most frequently found category of marine debris across all research stations. This category of debris displayed dominance during second transition season. Styrofoam accounts for the highest percentage of plastic debris found at all stations. The density and distribution of marine debris may be affected by oceanographic variables like seasonal winds, currents, tides, and differences in ecosystems. In addition, efforts to clean up marine debris are a significant factor in the variations of marine debris observed at each station.

ACKNOWLEDGMENT

This research was supported by a grant from the microSEAP UKRI Natural Environment Research Council (NERC) funding scheme [No. NE/V009516/1]. The authors would like to express their gratitude for the provided funding.

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