Jurnal Teknologi Perikanan dan Kelautan
Vol. 17 No. 2, May 2026: 253-264

ISSN: 2087-4871
EISSN: 2549-3841
DOI: https://doi.org/10.24319/jtpk.17.253-264



# SEASONAL VARIATION AND MACROPLASTIC COMPOSITION ON TIDUNG ISLAND BEACH, KEPULAUAN SERIBU

# VARIASI MUSIMAN DAN KOMPOSISI MAKROPLASTIK DI PANTAI PULAU TIDUNG, KEPULAUAN SERIBU

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(Received May 16, 2025; Revised March 3, 2026; Accepted May 27, 2026)

## ABSTRACT

The accumulation of macroplastics is strongly influenced by seasonal variation and poses a serious threat to the sustainability of marine ecosystems and local economies, particularly on small islands such as Tidung Island of the Seribu Islands. This study aims to examine the effect of seasonal variations on the composition and characteristics of macroplastic polymers in the coastal area of Tidung Island. Sampling was conducted periodically during the west monsoon (January–February 2022) and east monsoon (June–August 2022) at two coastal locations. Macroplastics collected in a 5 × 30 m transect were identified by polymer composition using FTIR-ATR. Abundance data were then analyzed using the non-parametric Kruskal-Wallis statistical test. The results showed that macroplastic accumulation in the west monsoon (0.156 units/m$^2$ and 2.006 g/m$^2$) was higher than in the east monsoon (0.073 units/m$^2$ and 1.759 g/m$^2$), with a significant difference ($p = 0.04$, $p < 0.05$). These results indicate that rainfall and seasonal current patterns influence the accumulation of macroplastics on the beach. The dominant type of macroplastic found was single-use plastics (wrappers and sachets, 62%). Polymer analysis identified polyethylene (PE), rubber, and polypropylene (PP) as the main components. The waste originated not only from tourism activities and local settlements but also from other locations transported here by the currents.

Keywords: macroplastics, polymers, seasonal variation, single-use plastics, Tidung Island

## ABSTRAK

Akumulasi makroplastik sangat dipengaruhi oleh variasi musiman dan menjadi ancaman serius bagi keberlanjutan ekosistem laut dan ekonomi lokal, khususnya di pulau kecil seperti Pulau Tidung, Kepulauan Seribu. Penelitian ini bertujuan mengkaji pengaruh variasi musiman terhadap komposisi dan karakteristik polimer makroplastik di wilayah pantai Pulau Tidung. Pengambilan sampel dilakukan secara berkala selama musim barat (Januari–Februari 2022) dan musim timur (Juni–Agustus 2022) di dua lokasi pantai. Makroplastik yang dikumpulkan dalam luasan transek 5 × 30 m, diidentifikasi komposisi polimer penyusunnya menggunakan FTIR-ATR. Data kelimpahan kemudian dianalisis menggunakan uji statistik non-parametrik Kruskal-Wallis. Hasil menunjukkan bahwa akumulasi makroplastik pada musim barat (0,156 unit/m$^2$ dan 2,006 g/m$^2$) lebih tinggi daripada musim timur (0,073 unit/m$^2$ dan 1,759 g/m$^2$), dengan perbedaan signifikan $p = 0,04$ ($p < 0,05$). Hasil tersebut menunjukkan bahwa curah hujan dan arah pola arus musiman berpengaruh terhadap akumulasi makroplastik di pantai. Jenis makroplastik yang dominan ditemukan berupa plastik sekali pakai (bungkus kresek dan sachet, 62%). Analisis polimer mengidentifikasi polietilen (PE), karet, dan polipropilen (PP) sebagai komponen utama. Sampah tidak hanya berasal dari aktivitas wisata dan pemukiman lokal, tetapi juga bawaan dari tempat lain yang terbawa arus.

Kata kunci: makroplastik, plastik sekali pakai, polimer, Pulau Tidung, variasi musiman

## INTRODUCTION

Marine pollution due to plastic waste has become a global issue in recent decades and requires urgent management action. An estimated 11 million tons of plastic enter the oceans annually, and this amount could triple by 2040 if no significant action is taken to address current plastic waste production and management systems (Jambeck *et al.* 2015; Borrelle *et al.* 2020). Macroplastics (> 5 mm in size) are among the most common forms of plastic waste, posing a physical threat to marine life, such as ingestion and entanglement, as well as socio-economic losses in the tourism and fisheries sectors (Mueller *et al.* 2022). Methodologically, macroplastic monitoring can be conducted through relatively standardized transect surveys and manual collection (Lippiatt *et al.* 2013), without the need for advanced laboratory analysis as in microplastic studies (Hidalgo-Ruz *et al.* 2012). Ecologically, macroplastics are a source of microplastic formation through fragmentation processes in coastal environments (Andrady 2011). Therefore, controlling macroplastics is a crucial effort to prevent long-term plastic pollution.

Small islands in Indonesia, including Tidung Island in the Seribu Islands, are vulnerable to the accumulation of stranded plastic waste due to their location along ocean currents and increased tourism activity, while local waste management systems remain limited (Salamena *et al.* 2023; Vriend *et al.* 2021). Despite being popular tourist destinations that directly contribute to the local economy, the high number of tourists also leads to increased plastic waste. Therefore, studying the characteristics and distribution of macroplastics in areas like Tidung Island is crucial as a basis for developing coastal management policies to support sustainable and environmentally friendly tourism.

The presence and distribution of plastic waste are inextricably linked to coastal dynamics. Oceanographic factors such as current patterns, meteorological factors like seasonal wind direction and rainfall, and anthropogenic activities play a role in determining the volume and composition of plastic waste accumulated on coastal land (Cordova and Nurhati 2019). In tropical regions like Indonesia, the differences in characteristics between the west and east monsoons are likely to influence the composition and accumulation of stranded waste throughout the year (Purba *et al.* 2021). Similar conditions are suspected to occur in the Tidung Island area. Extensive research on plastic waste in Indonesia has been conducted, but it still prioritizes quantitative measurements and the spatial distribution of plastic waste in open waters or major beaches (Cordova *et al.* 2022; Veiga *et al.* 2023). Several studies have highlighted the seasonal dynamics of waste on small islands, such as Rambut Island (Rahman *et al.* 2024), Tunda Island (Maharani *et al.* 2020), and Ambon (Salamena *et al.* 2023), and have demonstrated the high vulnerability of small islands to seasonal macroplastic accumulation. The marked differences between small island ecosystems and mainland coastal ecosystems, both in terms of geomorphology, local ocean currents, and ecosystem carrying capacity for waste loads, create a gap in scientific data regarding the impacts and seasonal dynamics of macroplastics on small islands (Lasut *et al.* 2021). For example, variations in the types and volumes of macroplastic waste in conservation areas such as Rambut Island indicate high marine waste pressure due to spatial connectivity with human activities on surrounding islands (Rahman *et al.* 2024). Research on seasonal variations and their relationship to macroplastic waste composition on the beaches of Tidung Island, Seribu Islands, is expected to reveal the phenomenon of plastic waste variability to support adaptive and ecosystem-based coastal management policies.

## METHODS

### Time and location

Macroplastic sampling was conducted once a month during two main seasons: the west monsoon (January–February 2022) and the east monsoon (June–August 2022). Sampling was conducted at two locations on the coast of Tidung Island: one in the southern part of Big Tidung Island and the other in the southern part of Little Tidung Island (Figure 1). The selection of the sampling location on the southern coast of Tidung Island was based on several considerations. Hydrodynamically, the dominant ocean currents and winds in the Seribu Islands tend to direct waste accumulation to the southern part of the island (Mustikasari and Rustam 2019). Furthermore, the sloping morphology of the coast and the presence of tourism and residential activities in the surrounding area increase the potential for macroplastic accumulation. Better location accessibility also plays a supporting factor in carrying out sampling activities effectively and safely.

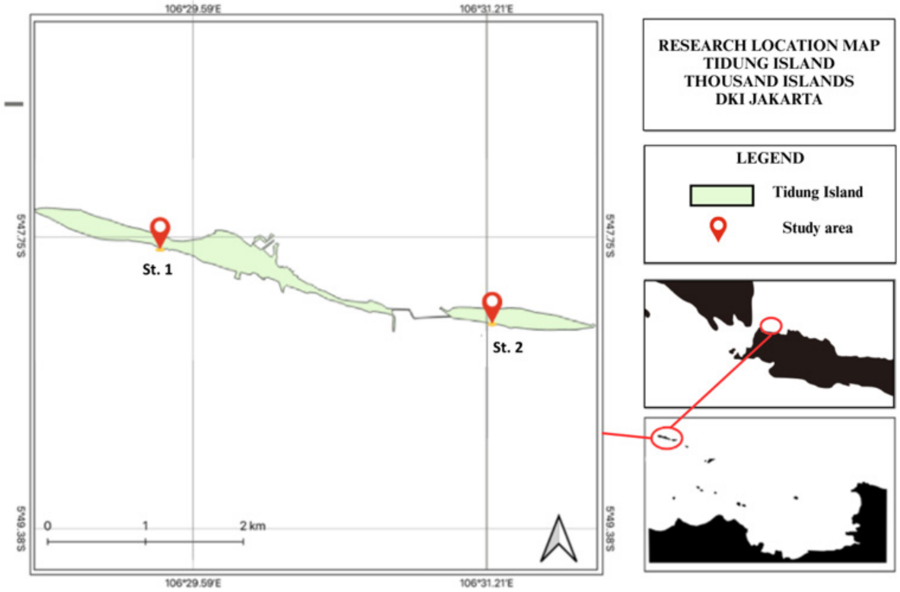


Figure 1. Map of research location and sampling points on the coast of Tidung Island, Seribu Islands.

**Sample collection and identification**

The sample collection process was carried out using a census method, namely by collecting all types and quantities of macroplastics found within a predetermined transect area. The transect area was set at 30 m × 5 m (Figure 2), following standards commonly applied in coastal debris characterization research (Lippiatt *et al.* 2013). The transect size was adjusted to the conditions and area of the beach at each sampling point. All macroplastic debris (> 5 mm) within the transect was collected manually using gloves for safety (Lechthaler *et al.* 2020). Next, the macroplastics were cleaned, classified, counted, and weighed. The macroplastic classification (Table 1) was adopted from the research of Cordova *et al.* (2022), which classifies macroplastics based on their type and use.

The calculation of the estimated density of stranded macroplastics was carried out by calculating the number of units or weight per square meter of the transect area using the following abundance equation:

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

where D is the macroplastic abundance (units/m$^2$ or g/m$^2$), n is the number of units or weight of macroplastics, w is the transect width (m), and l is the transect length (m).

During five sampling periods, cleaned and dried macroplastic samples were taken. Ten small pieces of plastic were then sampled to identify the polymer composition of the plastic using an Agilent Cary 630 Fourier Transform Infrared Spectrometer (FT-IR), with Diamond Attenuated Total Reflectance (ATR), and Microlab FTIR software. The identification process was conducted at the Environmental Chemistry Laboratory, Oceanography Research Center, National Research and Innovation Agency (BRIN). Polymer analysis used an FTIR-ATR device with a resolution of 4 cm$^{-1}$ over the 650–4,000 cm$^{-1}$ range and 16 scans per analysis (Cordova *et al.* 2022). Measurements were repeated 2–3 times on several sample sections to ensure consistency of identification results.

**Statistical analysis**

Statistical analysis was performed using non-parametric test methods with the help of PAST (Paleontological Statistics) software version 4.11. The Kruskal-Wallis test was used to evaluate differences in macroplastic abundance and weight between seasons. Differences were considered significant at $p < 0.05$ (Cordova *et al.* 2022).

## RESULTS AND DISCUSSION

**Abundance and seasonal variation of macroplastics**

The number of macroplastics collected at the two observation stations during the sampling period was 517 units, weighing 8,471 g. The abundance of macroplastics at Station 1 was greater than that at Station 2, both in units and weight (Figure 3A, C). The average density at Station 1 was 0.29 ± 0.098 units/$m^2$ with a mean weight of 2.07 ± 0.845 g/$m^2$. At Station 2, the density was 0.07 ± 0.042 units/$m^2$ with a mean weight of 1.69 ± 1.033 g/$m^2$. The Kruskal-Wallis test also showed that there was no significant difference between the average density and weight between stations, with p values of 0.1076 and 0.0575, respectively, at a significance level of $p < 0.05$.

The macroplastics accumulated on the two beaches of Tidung Island are still lower in abundance compared to those in a study conducted by Fruergaard *et al.* (2023) on the south-central coast of Nha Trang city, Vietnam. The number of macroplastics originating from the area reached 4,754 units and weighed 27 kg, with an abundance of 19.8 ± 19.5 units/$m^2$ and a weight of 116 ± 226 g/$m^2$. Similarly, a study conducted by Jang *et al.* (2018) on the coast of Sri Lanka noted that the average abundance of macroplastic particles was 4.1 ± 9.2 units/$m^2$ and a weight of 175 ± 538 g/$m^2$. The intensity of human activity is thought to be the main factor influencing macroplastic accumulation in coastal environments. The south-central coast of Nha Trang City, Vietnam, is located in an area adjacent to densely populated areas and coastal fisheries zones. This area is considered an area with high levels of contamination due to the presence of rivers, ports, and housing (Fruergaard *et al.* 2023). Similarly, on the coast of Sri Lanka, most of the macro-waste accumulated in the area originates from local waste carried by rivers and cities (Jang *et al.* 2018). Unlike these two locations, Tidung Island is a small island relatively far from the mainland of Jakarta.

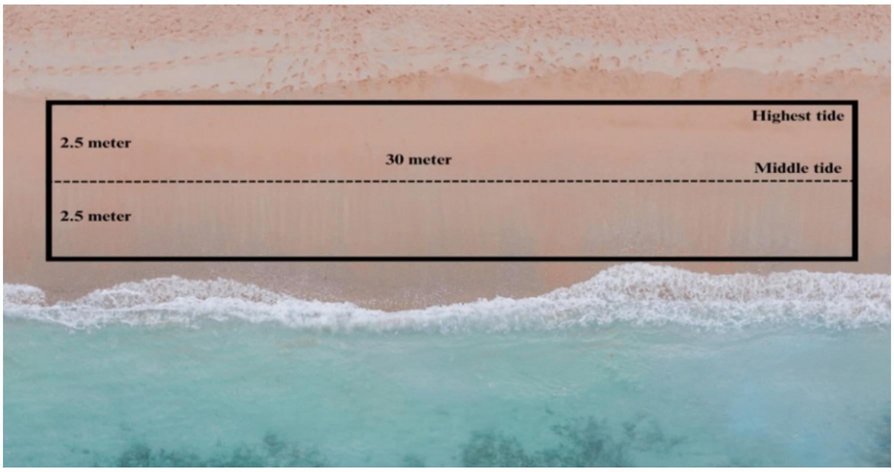


Figure 2. Illustration of a 30 m × 5 m macroplastic sampling transect on Tidung Island beach.

Table 1. Classification of types of plastic and rubber waste based on their use.

| No | Classification of Plastic and Rubber |
|---|---|
| 1 | Balls, tires, balloons, and scraps |
| 2 | Plastic bottles and plastic caps |
| 3 | Plastic cups |
| 4 | Cigarette filters |
| 5 | Carpets, sofa covers (house, car, motorcycle) |
| 6 | Plastic bags, plastic sachets |
| 7 | Rubber bands, rubber pieces |
| 8 | Medicine wrappers |
| 9 | Straws, cotton swabs, and similar items |
| 10 | Lunch boxes, spoons, and similar items |
| 11 | Used shoes, sandals, gloves, and scraps |
| 12 | Styrofoam |
| 13 | Rope, fishing line, fishing tackle, raffia |
| 14 | Cosmetic packaging, toiletries, and similar items |
| 15 | Sacks |

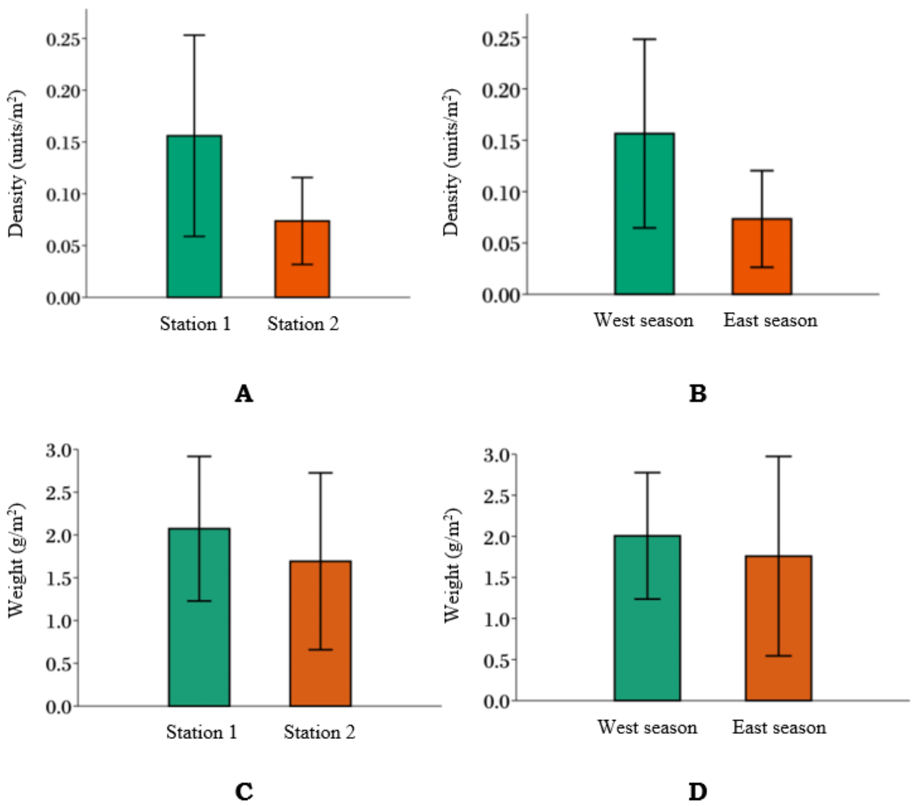


Figure 3. Average density and weight of stranded macroplastics based on observation station and season: density between stations (A), density between seasons (B), weight between stations (C), and weight between seasons (D).

The sampling period covered two seasons in Indonesia, namely the west monsoon (January–February) and the east monsoon (June–August). Seasonally, the average abundance and weight of macroplastics in the west monsoon were higher than in the east monsoon (Figure 3B, D). The average abundance and weight in the west monsoon were 0.156 ± 0.092 units/m$^2$ and 2.006 ± 0.77 g/m$^2$, respectively. In the east monsoon, the average abundance and weight of macroplastics were 0.073 ± 0.048 units/m$^2$ and 1.76 ± 1.21 g/m$^2$, respectively. The Kruskal-Wallis test results showed a significant difference between the west and east monsoons with a p-value of 0.04 ($p < 0.05$). This is similar to a study conducted by Kurniawan and Imron (2019) in the Wonorejo River estuary in Surabaya, which found that abundance values were higher during the west monsoon than during the east monsoon. Similarly, a study by Taryono *et al.* (2020) in the Cimandiri estuary showed that macroplastic accumulation was higher during the west monsoon than during the east monsoon. This is thought to be due to rainwater runoff, a key factor in carrying waste from land to the nearby marine ecosystem.

The accumulation of macroplastics on the coast of Tidung Island is closely related to anthropogenic activities and seasonal variations that influence rainfall intensity, current patterns, and seasonal wind direction in the surrounding area. Tidung Island, as a small inhabited island near Jakarta, is a frequent tourist destination. Tourism activities and coastal settlements are the main contributors of macroplastics directly to the beach through plastic waste from visitors and unmanaged domestic waste, which is then left on the shoreline and can accumulate in large quantities. At Station 1, waste accumulation results from a combination of tourism and household activities, while at Station 2, the beach is used solely for tourism. Macroplastics discarded in tourist areas generally come from food waste, beverage bottles, food packaging, disposable recreational equipment, and plastic bags and containers. Various studies have been conducted on macroplastic accumulation in tourist areas, for example, at tourist beaches in Zanzibar, Tanzania (Maione 2021), and Pintu Kota Beach, Ambon City (Kubangun *et al.* 2024). Higher waste accumulation in densely populated areas has also been documented at Santa Marta Beach, Colombia (Garcés-Ordóñez *et al.* 2020) and Airlouw Beach, Ambon City (Kubangun *et al.* 2024).

Tidung Island is located in the Java Sea and is influenced by seasonal ocean currents. In general, this area is influenced by the west and east monsoons (Tjasyono *et al.* 2008). The west monsoon is usually accompanied by high rainfall and strong currents. This high rainfall can increase plastic waste runoff from the mainland into the sea. Conversely, the east monsoon is a dry season with very low rainfall. All macroplastics entering the sea can migrate to other areas, including Tidung Island. This condition is reflected in the higher macroplastic density during the west monsoon compared to the east monsoon, in line with findings on various Indonesian coasts that confirm the role of monsoons, rainfall, and ocean currents as the main drivers of coastal debris accumulation (Cordova and Nurhati 2019; Kurniawan and Imron 2019). Therefore, this seasonal variation likely plays a significant role in the increase in macroplastic density. On the other hand, during the west monsoon, tourism activity is generally less intense than during the east monsoon, when sea conditions are relatively calm and favorable for tourism. The influence of seasons on macroplastic waste has also been previously studied in other regions by Veiga *et al.* (2023) and Rahmania *et al.* (2021). Veiga *et al.* (2023) emphasized that macroplastic distribution in Indonesia is strongly influenced by rainfall and urban drainage conditions, particularly during the rainy season. High rainfall during the west monsoon (January–February 2022), with an average of 10.37 mm, is thought to have increased runoff from nearby land, carrying macroplastic waste toward the southern coast of Tidung Island (BMKG 2022). This condition is also influenced by seasonal current patterns, which during the west monsoon predominantly move from the northwest (north coast of Java) to the east-southeast (south coast of Tidung Island) at an average speed of 21.06 cm/s. During the east monsoon (June–August 2022), rainfall intensity weakened to 3.79 mm, and the seasonal current direction also shifted from the southeast to the west-northwest, although the average speed reached 32.5 cm/s. This resulted in a decrease in river runoff, and the current direction also tended away from the coast of Tidung Island. Similar conditions also occurred on islands surrounding Banten Bay (Rahmania *et al.* 2021), showing a significant increase in macroplastic volume and density during the summer season.

**Types of macroplastics**

A total of 517 pieces of macroplastics were recorded, weighing 8,471 g, accumulated on the beaches of Tidung Island. The dominant types of macroplastics found were plastic bags and sachets, accounting for 62% of the total plastic waste composition (Figure 4). Other significant types included Styrofoam at 12%, followed by carpets or sofa wrappers at 7%, and shoes, used sandals, gloves, and their scraps at 6%. Meanwhile, other types of waste, such as plastic cups, bottles, and plastic lids, as well as rope or raffia, each contributed only 1–3%. Several other categories also accumulated on the beaches of Tidung Island, albeit in smaller percentages.

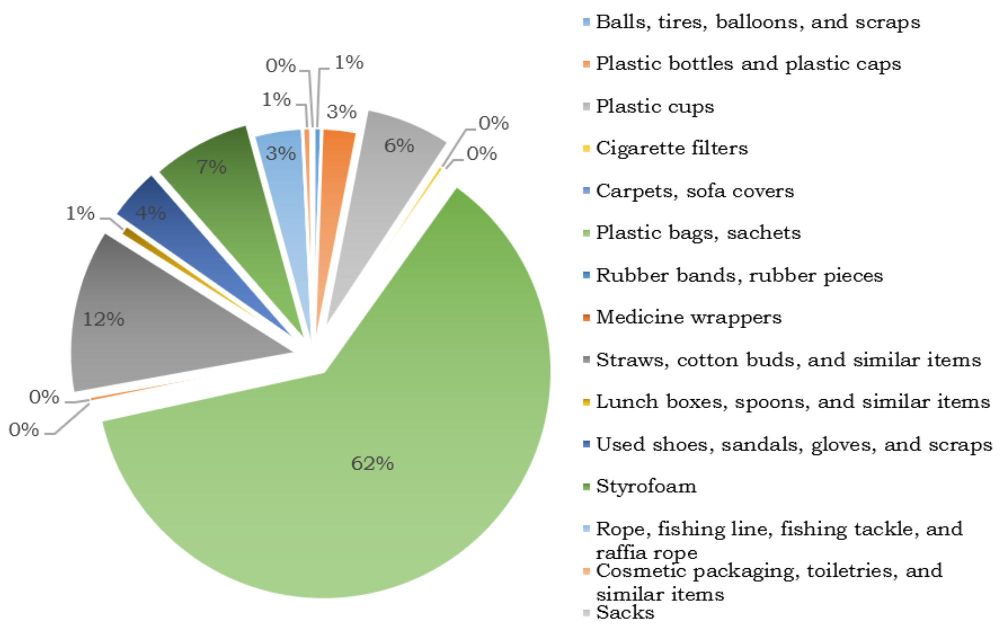


Figure 4. Percentage of accumulation of macroplastic types found on Tidung Island Beach.

Seasonal variations were observed significantly for several types of macroplastics, with relatively similar distribution patterns. During the west monsoon, waste accumulation tended to be higher compared to the east monsoon (Figure 5). The most dominant types of macroplastics in both seasons were plastic bags and sachets, reaching 212 units in the west monsoon and 107 units in the east monsoon. This indicates that single-use plastics are a major contributor to the accumulation of plastic waste on Tidung Island Beach. Other types, such as straws, Styrofoam, and plastic cups, also showed less accumulation during the east monsoon. A study by Yona *et al.* (2023) stated that 80% of the macroplastic waste found on Malang Regency Beach was single-use waste, consisting of straws, plastic wrappers, and Styrofoam. Similarly, research by Cordova *et al.* (2022) found that single-use plastics and multilayer plastics, such as sachets, were the most prevalent on all Indonesian beaches. The similarity in the composition of these macroplastic types indicates that macroplastics in coastal areas of Indonesia predominantly originate from domestic consumption patterns and tourism activities rather than industrial activities.

Tidung Island is a tourist destination that receives thousands of visits every year, which is generally accompanied by an increase in consumption of single-use plastic, such as drink bottles, plastic cups, and food bags. Guittard *et al.* (2023) report that small-scale tourist areas, including tropical islands, experience significant pressure from plastic waste, mainly due to the use of single-use products by tourists that are not adequately managed. Apart from originating from local activities, single-use plastic also has the potential to enter coastal areas through sea transportation mechanisms as it is lightweight and highly buoyant. Types of plastic in the form of thin films and low-density plastics will be more easily carried by ocean currents (Kumar *et al.* 2021). Another study by Chen *et al.* (2021) emphasizes that global ocean surface currents contribute to the formation of plastic waste accumulation zones, both in the open sea and in coastal waters. This is in line with the study conducted by Lim *et al.* (2023) on several beaches in the Malacca Strait, who found that the distribution of macroplastics such as food wrappers and plastic containers was influenced by ocean currents and wind exposure, which allowed the waste to be carried from the open sea to the coastline.

The presence of macroplastic waste in coastal ecosystems not only disrupts the aesthetics and comfort of tourism activities but also impacts environmental health and threatens the sustainability of coastal biota. A study by Tsai *et al.* (2021) shows that implementing an effective waste management system is an effort to improve environmental cleanliness and comfort. Socially and economically, the accumulation of waste that is not properly managed has the potential to damage the image of a destination, reduce tourist interest, and weaken the local economy, which is heavily dependent on the tourism sector. This aligns with the findings of Lukoseviciute and Panagopoulos (2021), who emphasized that coastal environmental quality is a key indicator of tourist perceptions of a destination. Therefore, macroplastic waste management must be collaborative, involving the government, the community, tourism businesses, and tourists themselves. Inocente *et al.* (2023) also emphasized that public understanding of the environmental impacts of plastic waste is crucial for the effective implementation of management policies. These findings suggest that macroplastic waste management in coastal tourism areas needs to be directed at reducing the use of single-use plastics, taking into account not only local sources and external contributions through oceanographic dynamics but also as an important prerequisite for realizing environmentally friendly, ethical, and sustainable tourism in the long term.

**Macroplastic polymers**

Analysis of macroplastic polymers washed ashore on Tidung Island showed the presence of plastic polymers (Table 2). Polyethylene was found to be the most dominant polymer, accounting for 34%. Polypropylene was also significantly detected at 19%. Furthermore, polyethylene terephthalate (PET) and ethylene terpolymer also contributed to the detected polymers, accounting for 15% and 11%, respectively. The types of polymers detected reflect the origins of everyday products. Compa *et al.* (2022) reported that PE was the most dominant polymer found in the Western Mediterranean Sea. PE polymers are widely used in single-use plastic packaging and flexible packaging. A study by Ryan (2020) found that PP polymers were the most dominant polymer found on the West Coast of Africa. Both polymers originate from food containers and household appliances. Both polymers are very light, making them easily carried by ocean currents and carried to nearby beaches. Furthermore, a study by Sandra and Radityaningrum (2021) found PET originating from bottles and food containers. This PET polymer can contribute to environmental pollution due to its slow degradation rate and potential to fragment into microplastics (Husnalia *et al.* 2023).

Seasonal variations in the composition of plastic polymers on the coast of Tidung Island show a similar fluctuation pattern, with a higher proportion of the analyzed polymer types during the west monsoon compared to the east monsoon (Figure 6). This reflects an increase in plastic input during the west monsoon, likely influenced by the intensity of human activity and environmental factors such as wind direction and seasonal ocean currents. Polyethylene (PE) was recorded as the most dominant polymer type in both seasons, with a percentage of 20% in the west monsoon and decreasing to 15% in the east monsoon. Rubber and PP decreased from 12% and 11% to 8%, respectively, during the east monsoon. Meanwhile, PET showed a significant decrease from 10% to 6%, and ethylene terpolymer decreased from 6% to 5%. This pattern indicates that the increase in contaminated plastic waste during the west monsoon reflects not only the intensity of human activity but is also influenced by the dynamics of material transport and accumulation based on the physical characteristics of the macro-waste.

Plastics accumulated in coastal environments undergo a complex degradation process due to exposure to various environmental factors, such as ultraviolet (UV) radiation, oxygen, high temperatures, and mechanical abrasion from sand and waves. One of the main mechanisms of this degradation is photo-oxidation, a UV-induced oxidative reaction on polymer chains that causes the breaking of molecular bonds, the appearance of microcracks, and discoloration of the material (Andrady *et al.* 2022). This process generally occurs on exposed coastal surfaces and is exacerbated by extreme environmental conditions. Furthermore, mechanical fragmentation due to friction with sand and wave activity accelerates the breakdown of large plastics into smaller fragments, or microplastics. Song *et al.* (2017) showed that the combination of long-term UV exposure and mechanical abrasion significantly accelerates the degradation of plastics such as polyethylene (PE) and polypropylene (PP), making them more brittle and prone to breakage. Resistance to degradation also varies between polymer types; for example, polyethylene terephthalate (PET) tends to be more UV-stable but still experiences structural damage over time. Dimassi *et al.* (2022) added that this degradation process not only changes the physical form of plastic but also produces toxic additive compounds from fragmentation, which have the potential to chemically pollute the ecosystem. Thus, differences in plastic polymer composition between seasons not only reflect variations in sources and intensity of human activities, but also reflect the dynamics of environmental degradation influenced by the physical characteristics of polymers and coastal conditions, which ultimately determine the sustainability and ecological impact of plastic residues in coastal ecosystems.

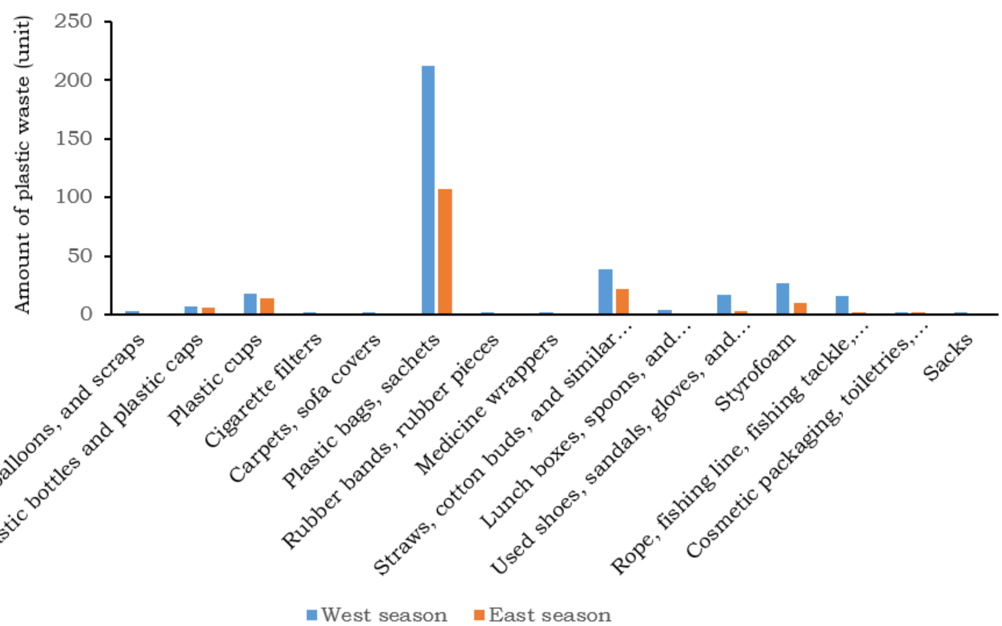


Figure 5. Seasonal variation of macroplastic types on Tidung Island Beach.

Table 2. Types and percentages of macroplastic polymers found on Tidung Island Beach.

| No | Types of Polymers | Percentage (%) |
|---|---|---|
| 1 | Polyethylene (PE) | 34 |
| 2 | Rubber | 20 |
| 3 | Polypropylene (PP) | 19 |
| 4 | Polyethylene Terephthalate (PET) | 15 |
| 5 | Ethylene Terpolymer | 11 |

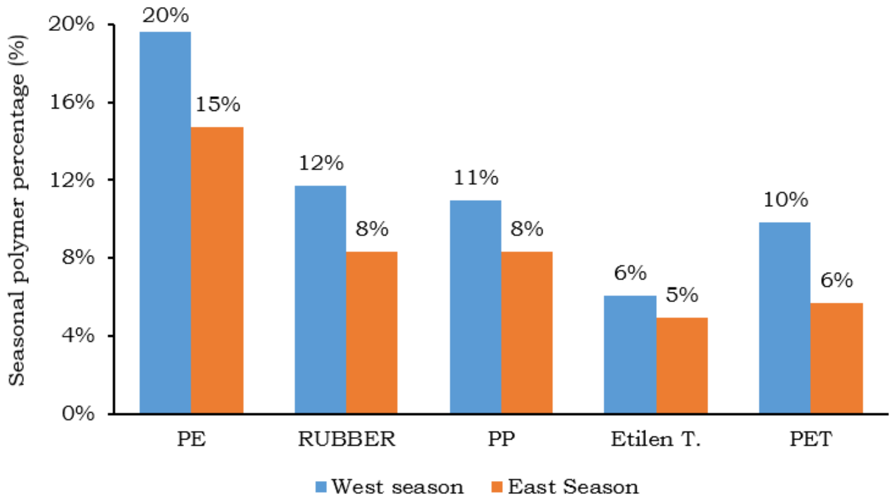


Figure 6. Seasonal variations in macroplastic polymer composition on Tidung Island Beach.

## CONCLUSION

The presence of macroplastics indicates a seasonal influence, as evidenced by higher densities during the west (rainy) season compared to the east (dry) season. The predominance of macroplastics in the form of food wrappers indicates that the source of the waste is not only tourism activities on Tidung Island, but also waste carried by ocean currents from other locations. Effective management of macroplastic waste on Tidung Island through integrated monitoring and community-based policies is crucial for maintaining the quality of the coastal environment and supporting the sustainability of marine tourism activities.

## ACKNOWLEDGMENT

Thanks to the UKRI Natural Environment Research Council (NERC) for funding this research through the microSEAP program "Microbial Transformation of Plastics in SE Asian Seas: A Hazard And A Solution" under Grant number [No. NE/V009516/1].

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