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Macroplastic pollution in mangrove forests of Tangub City, Panguil Bay, Philippines

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Abstract. *Paculba LSL, Mabida RCAC, Perico GCM, Magdayo Jr ED, Acot Jr FT. 2024. Macroplastic pollution in mangrove forests of Tangub City, Panguil Bay, Philippines. Nusantara Bioscience 16: 251-262.* Plastic pollution poses a growing threat to coastal ecosystems. In the Philippines, studies on macroplastic pollution in mangrove forests are limited. This study was therefore conceptualized to assess the extent of macroplastic litter in the mangrove forests of Tangub City, Misamis Occidental, Philippines. The objectives encompassed on determining the count, composition, weight, and polymer type of collected macroplastics, quantifying and comparing the density of macroplastic litter, assessing the clean-coast index, and investigating the impacts of macroplastic litter in mangrove forests. A 50-meter transect line perpendicular to the shore with three 10m×10m quadrats was delineated in the sampling areas. Macroplastic litter collection was done during eight non-consecutive days in in September-October 2023. Results found that *Sonneratia alba* Sm. with its aerial root structure dominated in San Apolinario trapped more plastics. Food packaging accounted for 48.7% of the composition, with Low-Density Polyethylene (LDPE) being the most common polymer type at 44%. The highest macroplastic density was 0.20 items/m² for San Apolinario. While plastic density varied across sites despite similar cleanliness ratings, the distribution remained consistent throughout the mangrove forests indicating no significant differences in areas (p=.45). Moreover, findings showed that plastic litter harmed the mangrove forests as the pneumatophores were smothered, the branches were twisted, and the stems were damaged disrupting the mangroves' structure. This study highlights the importance of understanding plastic pollution in mangroves to develop effective waste management and conservation strategies.

Keywords: Food packaging, macroplastic litter, mangrove forest, plastic pollution

INTRODUCTION

Plastics have become versatile materials with a wide range of applications across various sectors (Baynes et al. 2021). The widespread use of single-use plastics (trash bags, shopping bags, etc.) unfortunately fuels plastic pollution due to improper disposal (Khoaele et al. 2023). This surge in plastic waste has severe consequences, leading to plastic pollution as a global environmental catastrophe and a rising environmental problem (Rochman et al. 2013). Plastic pollution is particularly concerning due to the persistence of plastic in the marine environment (Landrigan et al. 2020). These materials can linger for extended periods, with varying persistence depending on factors like size, polymer type, shape, and density (Hidalgo-Ruz et al. 2012; Eriksen et al. 2014; Sajorne et al. 2021; Inocente and Bacosa 2022; Requiron and Bacosa 2022). This extended presence, combined with transport by currents, and wind, and its presence in various land- and sea-based sources, ultimately leads to the widespread occurrence of plastic residues throughout the world's oceans (Lebreton et al. 2012; Van Sebille et al. 2012; Do Sul et al. 2014; Dris et al. 2016).

The Philippines is responsible for over one-third (36%) of plastic inputs worldwide (Ritchie and Roser 2018). It ranked third globally in plastic waste emissions, contributing approximately 0.28 to 0.75 million tons of plastic waste annually. This was part of a larger issue where over 466 of the 1,656 rivers worldwide collectively deposited more than 0.36 million tons of plastic waste each year into the environment (Jambeck et al. 2015; Braganza 2017). The increased prevalence of disposable plastic waste in the environment is caused by multiple factors, include inadequate recycling rates, challenges in waste collection, and the lack of consistent separation of plastic packaging in Local Government Units (LGUs) (Manas 2023). Also, the tropical country of the Philippines experiences significant annual precipitation (PAGASA 2021), which leads to the transportation of plastic debris from land to rivers through surface run-off, stormwater, and sewage, and eventually, the plastics are carried from the rivers to the seas and oceans (Li et al. 2020).

Plastic waste problem affects various ecosystems (Alava et al. 2023) including mangroves which are high risk of being polluted (Koop 2021). According to Garcia et al. (2014), the Philippines is renowned for having one of the largest coastlines in the world, stretching approximately 36,289 kilometers, which is particularly significant in tropical areas due to the abundance of mangroves. The country hosts at least half of the world's 65 mangrove species (Kathiresan and Bingham 2001; Goloran et al. 2020), which provide food for many fishes, invertebrates, and birds, as well as protection from coastal disasters (Alongi 2008). With their abundant prop roots, pneumatophores, and robust tree trunks, they provide great wave protection while simultaneously acting as natural traps for floating plastic garbage carried by tidal currents (Horstman et al. 2014; Norris et al. 2017; Martin et al. 2019; Duan et al. 2021). Plastics can get buried in the sediment or become hooked by mangrove branches, stunting their growth, and potentially harming the mangrove trees (Ali et al. 2021). In certain cases, it reduces oxygen penetration into the rhizosphere, causing mangrove suffocation (Smith 2012), which results in pneumatophore distortion or poor growth (Van Bijsterveldt et al. 2021). Furthermore, in a study conducted by Manullang (2020), macroscopic plastic waste has also been shown to directly hinder photosynthesis and entangle plant seedlings having a significant influence on plant survival in littered ecosystems.

Concerning these threats, there are several studies conducted to document the impacts of plastic wastes (Ryan 2015). However, the potential impact of plastic litter in the mangrove forests in the Philippines is far less studied. Plastic litter has been found in many mangrove areas in Tangub City and there is no data on the density, composition, classification, and possible impacts of macroplastics in mangrove ecosystem. Thus, this research was conceptualized to determine the count, composition, weight, and polymer type of collected macroplastics, quantify the density of macroplastic litter, assess the clean-coast index, compare the density of macroplastics litter found in three sampling sites, and investigate the impacts of macroplastic litter in mangrove forests. This study provides a baseline data on macroplastic contamination in the mangrove forests of Tangub City and to furnish policy recommendations to the concerned agencies to combat plastic litter in mangrove ecosystems.

MATERIALS AND METHODS

Study area

The study was conducted in Panguil Bay, specifically in Tangub City, Misamis Occidental (Figure 1). This bay is bordered by the provinces of Lanao del Norte to the east and Zamboanga del Sur and Misamis Occidental to the west (Israel et al. 2004). Covering approximately 18,000 hectares, it features a coastline that stretches 112 kilometers (70 miles). Tangub City, situated in the province of Misamis Occidental, is a coastal city spanning an area of 162.78 square kilometers and has a population of 68,389 residents. The coastal fringes of Tangub City are home to rich mangrove forests, comprising both naturally occurring and replanted mangroves. Despite ongoing restoration efforts, there are noticeable differences in the density and composition of these mangrove forests; some areas thrive while others are more sparse due to encroachment from informal settlements. For this study, three barangays—Lorenzo Tan, San Apolinario, and Mantic—were selected as sampling sites based on criteria such as accessibility, mangrove cover, and proximity to human habitation to minimize biases.

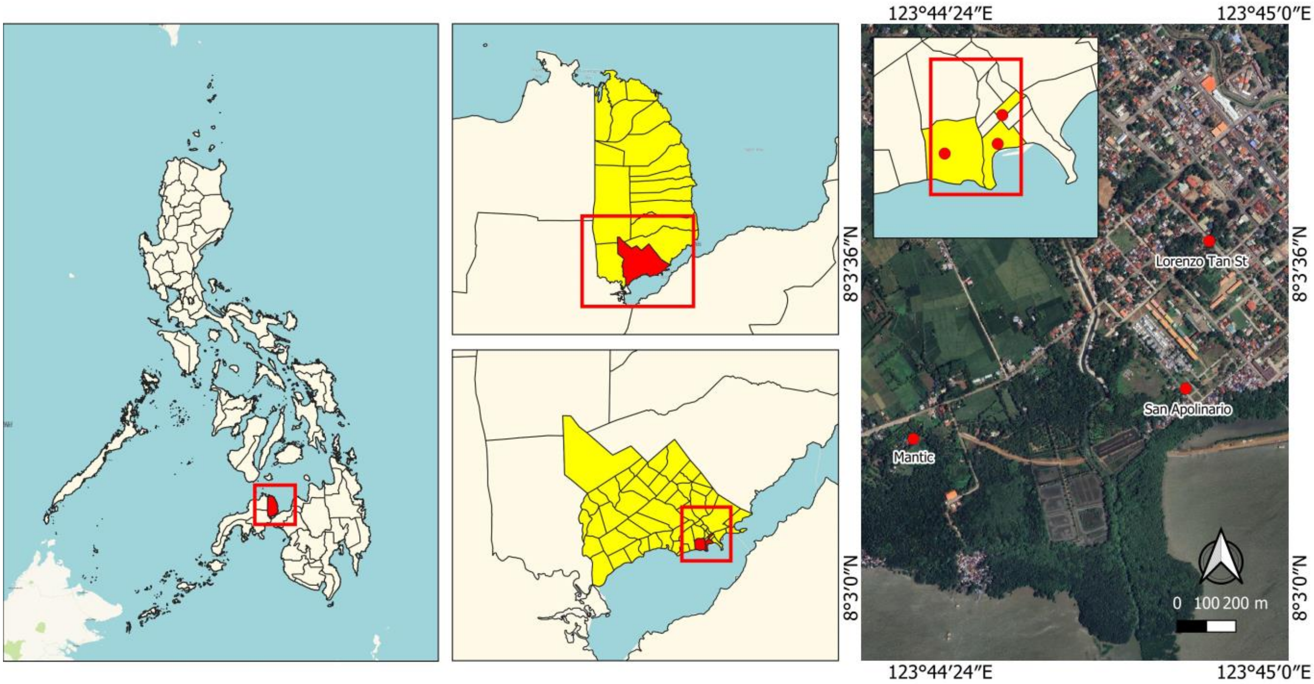

Figure 1. Map of Tangub City, Misamis Occidental, Philippines showing the three sampling areas

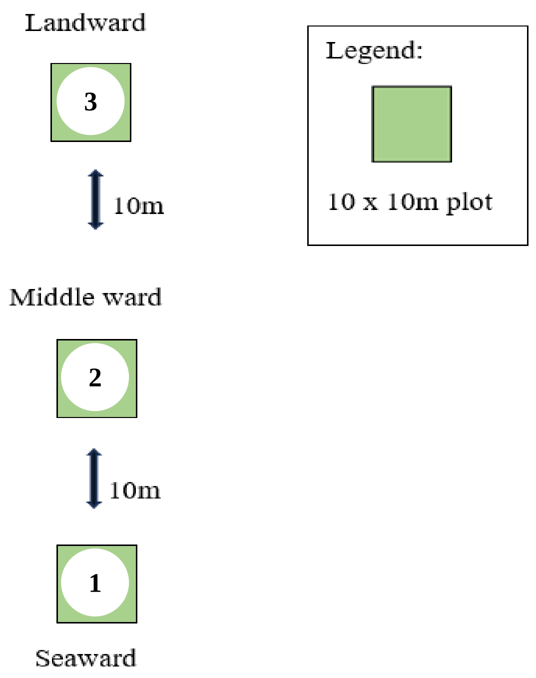

Figure 2. A schematic diagram for macroplastic litter sampling subplot in a 10x10 m^2 transect quadrat for the study of three mangrove forests in Tangub City, Philippines (zone 1. facing seaward side, zone 3. facing the landward side).

Data collection procedure

Identification of mangrove composition

The inventory of mangrove species composition was made in every study site before the collection of macroplastic litter. The basic mangrove identification survey was conducted during low tide to be able to identify the different species found in the three study sites (Abreo et al. 2020). All mangrove species found in all quadrats were counted, documented, and identified. The mangrove species were determined using the field guide manual to Philippine Mangroves Identification of Primavera et al. (2019) along with other online literature and researchers (Primavera et al. 2004).

Transect line and sampling station establishment

A 50-meter transect line perpendicular to the shore was employed in this study to collect samples of macroplastic litter. This method was based on the study by Suyadi and Manullang (2020) with modifications. On each transect, three 10 m×10 m (100 m^2) quadrats were laid out following the methods conducted by Yin et al. (2019). The subplots were 10 meters away making them not independent from each other. This method was modified from the study of Do Sul et al. (2014) (Figure 2).

Mangrove plastic litter collection

Plastic litter were collected at the lowest tide of the day. Plastic litter (macroplastics) found in the quadrat were manually collected by hand and placed in a labeled bag. The collected plastics were classified based on their plastic category following Syakti et al. (2017) and Kalnasa et al. (2019). The study employed a simultaneous collection of eight non-consecutive days to assess the accumulation of macroplastics in each area. Sampling collection was undertaken from the 20th day of September to the 14th day of October 2023. The collection specifically took place on Wednesdays to represent weekdays and Saturdays to represent weekends (Acot et al. 2022).

Plastic litter category and classification

The litter collected from each quadrat was properly washed and air-dried before its dry weight was measured with a digital top pan balance. Then, the items were manually counted and sorted into specific categories based on the study of Syakti et al. (2017) and Kalnasa et al. (2019) with some minor modifications: (a) food packaging, (b) disposable utensils (c) food containers (d) cloth, (e) napkin and diapers, (f) ropes, (g) cigarette, (h) plastic fragments, (i) plastic bags, (j) styrofoam, (k) medical waste, (l) sack, and (m) nylon fishing line, (n) footwear, (o) plastic bottle, (p) plastic caps, (q) fishing nets, (r) other bottle containers, (s) disposable lighters, (t) plastic cups (u) straws, (v) toiletries, (w) rubbers, (x) tetra packs, (y) metals, (z) glass, (aa) aluminum, (ab) electronics.

Macroplastic identification based on polymer type

The polymer types were identified according to the application. This method was based on the study of Andrady and Neal (2009), Namazi et al. (2017), and PlasticsEurope (2018). Most plastics were considered "hard-to-degrade" materials because of their corrosion resistance (Cole et al. 2011; Porta 2021).

Examining the impacts of plastic litter in mangrove forests

Direct observation with the aid of mobile cameras was employed to assess the visible impact of macroplastic litter in mangrove forests. The effects on mangroves were categorized into four categories (Damaged stem, Twisted Branches, Damaged pneumatophores and Smothering pneumatophores).

Data analysis

Composition of macroplastic litter prevalent in mangrove forests.

For the composition of plastic litter, the use of percent composition was calculated based on the study of Abreo et al. (2019) as shown in the equation below:

$$Composition\ analysis = \frac{Number\ of\ items\ in\ category}{total\ number\ of\ items\ in\ all\ categories} \times 100$$

Abundance and density of plastic litter

The density of the plastic litter collected was computed from the total number of items collected divided by the total sampled area which was expressed in no. of items/m^2 as shown in the equation below following the study of Abreo et al. (2019).

$$Density\ analysis = \frac{Number\ of\ plastic\ litter}{m^2}$$

Table 1. The classification of Clean Coast Index (CCI)

Clean Coast Index	Cleanliness rating	Visual assessment
0-2	Very clean	Very little debris is seen
2-5	Clean	Little debris is seen over a large area
5-10	Moderate	A few pieces of debris can be detected
10-20	Dirty	A lot of debris in the mangrove area
20+	Extremely dirty	Most of the mangrove area is covered with plastics

Clean Coast Index (CCI)

The Clean-Coast Index (CCI) was first proposed by Alkalay et al. (2007) as a tool to estimate the level of dirtiness or cleanliness of the coastal areas. It considered a range of factors, including the amount and type of litter present, as well as the level of public awareness and participation in clean-up efforts. This mathematical instrument was an easy way to avoid bias conducted by the assessor (Alkalay et al. 2007). Using the CCI evaluation, the total amount of plastic litter collected in the study was analyzed to qualitatively assess the cleanliness of each mangrove area. To ensure that the resulting value from the CCI equation did not fall between zero and one, a coefficient of k=20 was included in the equation as a multiplier. This was suggested by Alkalay et al. (2007) to ensure that the values generated do not fall between 0 and 1. The CCI was calculated as follow:

$$CCI = \frac{Total\ number\ of\ plastic\ items\ on\ transect}{Total\ area\ of\ transect} \times K$$

The final CCI numbers were used to determine the corresponding cost grade index. In accordance with the CCI scale, Table 1 shows the assessment of coastal beach cleanliness which is classified as follows: values ranging from 0 to 2 represent a state of being very clean, 2 to 5 indicate a clean condition, 5 to 10 suggest a moderately clean state, 10 to 20 denote a dirty condition, and values exceeding 20 indicate an extremely dirty state, where the majority of the beach is covered in plastic debris (Vlachogianni et al. 2018).

Statistical analysis

The collected data were analyzed using Jamovi statistical software version 2.4.11. To identify the significant difference between sites, a one-way Analysis of Variance (ANOVA) test was used. The density (items/m^2) ± SD was calculated, and values were evaluated as significantly different at $p<0.05$.

RESULTS AND DISCUSSION

Mangrove species composition

Mangroves are salt-tolerant trees that thrive along tropical and subtropical coastlines (Kesavan et al. 2021). It flourishes amid the tides, forming an intricate network of roots and branches that act as a natural barrier, effectively trapping objects carried by currents, such as floating plastic (Horstman et al. 2014; Norris et al. 2017). However, due to the differences in the physical structure of mangrove species, some species are more able than others to capture plastic litter (Luo et al. 2022). Among mangrove species, *bungalon* (*Avicennia marina* (Forssk.) Vierh.) can trap more plastics due to its distinct aerial root system, which includes sieve-like pneumatophores able to capture floating plastic debris (Martin and Duarte 2019). Conversely, the White mangrove (*Laguncularia racemose* (L.) C.F.Gaertn.) has no visible aerial roots that may not be able to retain plastic litter.

In this study, there were eight (8) mangrove species identified in the sampling areas: *pagatpat* (*Sonneratia alba* Sm.), *api-api puti* (*Avicennia alba* Blume), *bakauan-lalaki* (*Rhizophora apiculata* Blume), *saging-saging* (*Aegiceras corniculatum* (L.) Blanco), *lagiwliw* (*Acanthus ilicifolius* L.), *palaypay* (*Acrostichum aureum* L.), *tambigi* (*Xylocarpus granatum* J.Koenig) and *nipa* (*Nypa fruticans* Wurmb) (Table 2). Among the identified mangrove species, *pagatpat* (*S. alba*) was more apparent in Brgy. Lorenzo Tan and Brgy. San Apolinario. This species has an aerial root that grows upward (Costa et al. 2019) and can trap garbage (Siddiqui and Pandey 2013). Moreover, *A. alba* has pneumatophores with a knobby protrusion on their roots that effectively capture plastic waste. Understanding the plastic capture capabilities exhibited by various mangrove species is crucial in developing strategic actions to safeguard vital mangrove ecosystems from the detrimental effects of plastic pollution.

Table 2. Mangrove species composition and number of individuals in all sampling sites

Mangrove species	Lorenzo Tan	San Apolinario	Mantic
Pagatpat (*Sonneratia alba*)	13 (49%)	16 (100%)	0
Api-api puti (*Avicennia alba*)	2 (7%)	0	27 (71%)
Bakauan-lalaki (*Rhizophora apiculata*)	1 (4%)	0	0
Saging-saging (*Aegiceras corniculatum*)	2 (7%)	0	0
Lagiwliw (*Acanthus ilicifolius*)	0	0	6 (16%)
Palaypay (*Acrostichum aureum*)	3 (11%)	0	3 (8%)
Tambigi (*Xylocarpus granatum*)	3 (11%)	0	0
Nipa (*Nypa fruticans*)	3 (11%)	0	2 (5%)
Total number of species	7	1	4
Total strands	27	16	38

Table 3. Count of macroplastic litter collected in all sampling sites

Plastic category	Number of pieces	Composition (%)	Weight (g)
Food packaging	609	48.7	3320.86
Plastic bags	278	22.24	4071.28
Napkin/diapers	66	5.28	1754.98
Plastic cups	44	3.52	226.48
Plastic bottle	32	2.56	722.05
Sacks	30	2.40	3238.79
Glass	25	2.00	5284.25
Footwear	19	1.52	2929.59
Clothes	17	1.36	4067.65
Plastic fragments	16	1.28	396.56
Ropes	15	1.20	255.38
Nylon fishing line	14	1.12	259.2
Plastic caps	13	1.04	41.51
Fishing nets	12	0.96	673.45
Medical waste	9	0.72	73.35
Styrofoam	7	0.56	145.82
Aluminum	6	0.48	220.31
Food containers	4	0.32	183.49
Straws	4	0.32	23.22
Electronic	4	0.32	98.29
Disposable utensils	4	0.32	12.89
Toiletries	3	0.24	20.73
Disposable lighters	2	0.16	27.08
Metals	2	0.16	70.56
Rubbers	1	0.08	51.28
Others	14	1.12	260.07
Total	1250	100	28,419.39

Count, composition, and weight of collected macroplastics in all sampling sites

Macroplastic can be easily transported by natural forces throughout the environment, particularly in vulnerable ecosystems like mangrove forests. The findings from this study exemplify this concern, revealing a significant amount of plastic litter collected within just eight non-consecutive days across various mangrove sampling sites (Table 3). Out of 27 different types of plastic waste in all sampling sites, a total count of 1250 plastic items and a total weight of 28,429.11 g were collected. Out of the accounted macroplastics, 609 pieces (48.7%) of which were single-use plastics such as food packaging (e.g. sachet of shampoo, junk foods, candies, etc.). It was recorded to be the most abundant in terms of count, composition, and weight. According to the studies of Kalnasa et al. (2019), Paler et al. (2019), Esquinas et al. (2020), and Sajorne et al. (2021), in developing countries like the Philippines, readily available and affordable single-use food, products packaging, such as sachets, is the most common plastic waste and the primary contributor to the increasing adverse effects of plastic garbage.

Meanwhile, plastic bags were the second most abundant item collected, accounting for 278 pieces (22.2%) of all plastic waste items collected. While their affordability and lightweight nature make plastic bags a convenient choice for carrying groceries and other goods, they pose a significant threat to marine life, particularly species like seabirds and sea turtles. These animals, which feed exclusively at sea and exhibit non-selective surface foraging behavior, are especially vulnerable to plastic pollution, as evidenced by the high prevalence of plastic debris found in their stomachs (Besseling et al. 2015; Hardesty et al. 2015; Wilcox et al. 2015; Kumartasli and Avinc 2020).

Moreover, the results also highlight site-specific variations in waste composition. Each site exhibits its waste profile, with variations in the relative combination of factors that influence consumption patterns and waste generation in each area. Understanding these factors is essential for developing effective waste management strategies tailored to the specific challenges of each site. For instance, as shown in Figure 3, Lorenzo Tan (A) recorded numerous categories of plastic types (26), dominated by food packaging (30%). The presence of a fish port, tourist spot, and numerous variety stores likely contributes to this, as they rely heavily on single-use plastics. Additionally, the high proportion of disposable personal care products (napkins and diapers, 11%) suggests potential cultural influences or convenience-driven choices. On the other hand, in San Apolinario (B), with 24 types of plastics, food packaging emerges as the dominant waste component, making up 59% of the total waste. This high contribution can be attributed to factors like the concentration of food establishments, variety stores, and street food vendors and the lack of sustainable waste management practices, such as limited waste collection further exacerbating the issue. The significant contribution of plastic bags at 21% can be attributed to their availability and widespread use indicating a need for targeted interventions to reduce their usage and promote reusable alternatives. However, in Mantic (C), despite having the lowest plastic composition of 17, food packaging still emerges as the primary composition of waste, accounting for a substantial 61% of the total waste generated. Notably, the significant contributions of plastic bags (14%) and plastic cups (8%) can be linked to the popularity of take-out beverages and the consumption of beverages on the go.

Overall, the study suggests a general similarity in plastic waste composition likely influenced by factors like the local businesses which contributed to the prevalent usage of single-use plastic packaging in the areas and the flow of water that significantly connects the coastal areas in Tangub City. The data obtained underscore the need for comprehensive waste management strategies that address the entire waste stream, considering not only the highest contributors but also the smaller categories. A holistic approach should involve the potential for behavior change and the adoption of more sustainable practices, reducing plastic consumption, promoting recycling and reuse, implementing proper waste disposal systems, and fostering a circular economy.

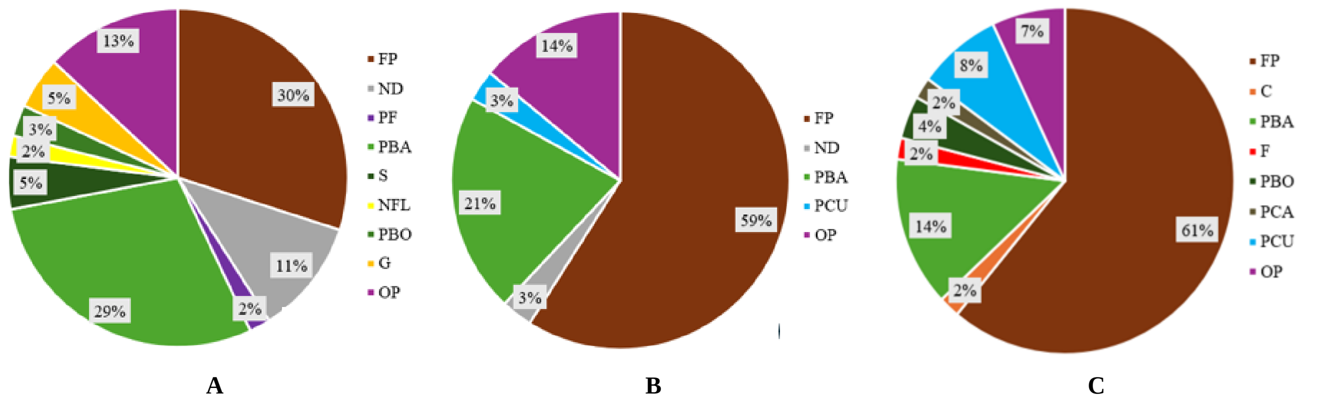

Figure 3. Composition of macroplastic litter of each site in Tangub City, Misamis Occidental, Philippines, i.e. A. Lorenzo Tan, B. San Apolinario, C. Mantic. Note: FP: Food Packaging, NP: Napkins and Diapers, PF: Plastic Fragments, PBA: Plastic Bags, S: Sacks, NFL: Nylon Fishing Lines, F: Footwears, PBO: Plastic Bottles, PCA: Plastic Caps, PCU: Plastic Cups, G: Glasses, OT: Other Plastics

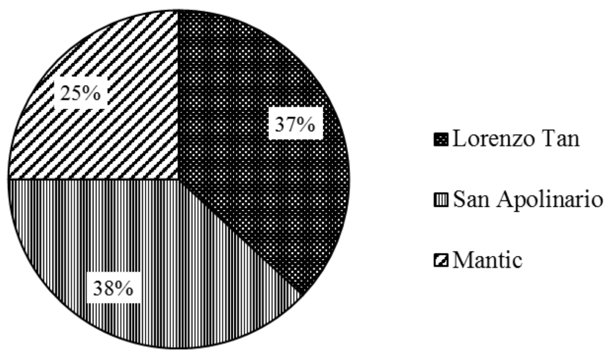

Figure 4. Overall total waste count in three sampling sites with corresponding percentage

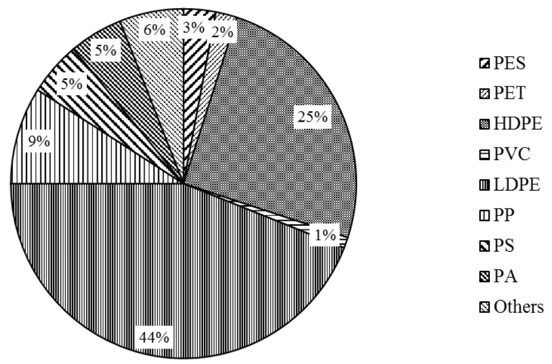

Figure 5. Polymer composition of macroplastics collected from all sampling sites

The total count of macroplastics from each sampling site (Figure 4) reveals the extent of plastic litter pollution across these environments. Among the three sampling sites, San Apolinario had the highest macroplastic litter collected with 480 items, accounting for 38% of the total waste. Following San Apolinario is Lorenzo Tan with 459 (37%) total waste, and Mantic had the lowest waste counts of 311 (25%). Some factors could explain the high waste counts in these sampling sites. In San Apolinario, due to its extensive mangrove cover, is predominantly dominated by the *S. alba* species, known for its aerial roots that effectively trap and retain plastic debris within the intricate structures of the mangrove habitat and the presence of numerous small convenience stores and mooring areas likely contributes to waste accumulation. Additionally, Barangay Lorenzo Tan exhibited a significant amount of plastic litter, characterized by the presence of stack macroplastics in the quadrat facing the landward side, along with the existence of a fish port and a scenic spot, which collectively contributed to the considerable volume of waste collected.

Meanwhile in Barangay Mantic, near the sampling area, an ongoing seawall construction serves as a barrier against debris, potentially reducing the likelihood of plastics reaching the mangrove area where they could accumulate. Additionally, Barangay Mantic is influenced by the plastic ban implemented by the city of Tangub, particularly on specific days. This ban has led to reduced plastic usage in the area.

Polymer classification of collected macroplastics

In this study (Figure 5), the plastics collected were further classified into 13 polymer types, which include Polyester (PES), Polyethylene terephthalate (PET), Polyethylene (PE), High-density polyethylene (HDPE), Polyvinyl chloride (PVC), Low-density polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), High-impact polystyrene (HIPS), Polyamides (PA) (nylons), Acrylonitrile butadiene styrene (ABS), Polycarbonate (PC), and Polytetrafluoroethylene (PTFE) (Shah et al. 2008; Halden 2010; Andrady 2011; Ghosh et al. 2013;). Findings presented in Figure 5, show that collected plastic wastes consist of PES, PET, PVC, LDPE, HDPE, PP, PA, PS, and others. The sampling areas were dominated by LDPE plastic waste, having 44%, which is attributed to its widespread usage in everyday items such as plastic bags, packaging materials, and disposable products. The convenience and versatility of LDPE contribute to its extensive presence in the waste stream. The other significant type of plastic dominated also in the areas was HDPE accounting for 25%. This polymer is known for its high strength-to-density ratio, chemical resistance, and impact strength (Wang et al. 2019). The high percentage of HDPE in the waste collected can be attributed to its widespread usage in packaging and durable goods. The durability and versatility of HDPE make it a preferred choice for many industries, leading to its significant presence in the waste stream (Kumar et al. 2021). The findings suggest that most of the plastics collected came from household or community settlements. While these plastics are useful to humans, they have also created an emerging environmental threat (Thompson et al. 2009; Olanrewaju and Oyebade 2019; Dumbili and Henderson 2020). According to the study of Lebreton et al. (2018), polyethylene-based plastics have been discovered in the marine environment since the early days of production, resulting in a global plastic crisis. The flexible and thin structure of plastic LDPE causes it to decompose quickly into microplastics (Devi et al. 2016), which can cause physical damage and harm to the environment and organisms in the water (Adithama et al. 2023). Furthermore, in a study by Shimao (2001) and Barnes et al. (2009), the widespread use of LDPE and HDPE has significant negative impacts on terrestrial and marine ecosystems, such as the obstruction of fish, birds, and marine mammals' intestines by plastic litter. Moving on to the other polymer types, PET (2%), PP (9%), PS (5%), PA (5%), and others (6%) make up the remaining percentages of the waste collected. The category of "Others" encompasses polymer types that may not be as prevalent but still contribute to the overall waste composition. This category includes various polymers that can be found in applications in different industries.

Understanding the composition of these polymer types in the waste stream is crucial for developing effective waste management strategies. It allows for targeted efforts in recycling, promoting sustainable alternatives, and reducing the environmental impact of plastic waste. By focusing on the highest contributors, such as LDPE and HDPE, and considering the characteristics and applications of other polymer types, it becomes possible to develop comprehensive waste management approaches that address the specific challenges posed by each polymer type.

Macroplastics density and Clean-Coast Index (CCI) analysis for cleanliness assessment

Table 4 shows the macroplastic litter density and Clean-Coast Index level across different locations. Among the three sites, San Apolinario had the highest density of 0.2 items/m^2, while Mantic, on the other hand, had the lowest overall macroplastic litter count of 311 pieces with a density of 0.13 items/m^2. Moreover, the results were further analyzed using the Clean-Coast Index to assess the level of cleanliness in the mangrove areas (Alkalay et al. 2007). The findings indicated that Lorenzo Tan, San Apolinario, and Mantic were comparatively clean, in which CCI ranging from 2 to 5.

However, it is important to note that the analysis focuses solely on macroplastics and does not consider other types of litter. To sustain the cleanliness and minimize the impact of plastic pollution, monitoring and waste management strategies should be continued in the areas. This includes not only addressing macroplastics but also considering other types of litter. By implementing comprehensive waste management practices and raising awareness about the importance of reducing plastic waste to maintain the cleanliness and contribute to a healthier coastal environment.

As illustrated in Figure 6, a detailed summary of every collection is presented. It depicts the quantity of plastic litter collected from three distinct mangrove areas across eight non-consecutive days. The results indicated that during the initial collection on Day 1, all sites exhibited a higher accumulation of plastics. This outcome was expected, as it represents the buildup of plastics over time in each respective area. Meanwhile, as observed there is considerable variation in the amount of litter collected, indicating fluctuations in collection over time. After the collection of stack macroplastic on Day 1, it was shown that Day 3 of the collection was found to have the highest total count with 187 items while the lowest count with 83 items was recorded on Day 6 of the collection.

Moreover, in comparing the three sites, the highest collection of plastic waste appears in San Apolinario on Day 2 which coincided with heavy rain and high tide in San Apolinario. The amount of plastic litter collection was affected with the transport of waste from river and canals along with heavy rains and high tide, also entanglement of waste in pneumatophores and branches in mangroves which likely the factors contributed to the accumulation of plastic debris in the coastal environment (Galgani et al. 2013; Veerasingam et al. 2016; Requiron and Bacosa 2022; Garcés-Ordóñez et al. 2023). During the low tide period in the afternoon, as the tide receded, a significant amount of plastic waste, including sachets and plastic bags, which had been washed ashore or carried by water currents, was observed caught in the pneumatophores of *S. alba* and was entangled in its branches especially the tree near in the seaward side.

Further research and analysis to gain a more comprehensive understanding of the specific factors contributing to the higher plastic collection in all areas is important. This knowledge can inform targeted interventions and strategies to mitigate plastic pollution in the areas and promote sustainable waste management practices.

Comparison of macroplastic litter density found in three sampling sites

The data presented in Table 5 reveals a comparison of macroplastic litter density across all sampling sites. Inferential statistics results show that there is no significant difference in plastic waste density across three sites, F $(2,12) = 0.82$, $p = 0.45$. This suggests that the distribution of macroplastic pollution is relatively consistent across the sampling sites. It could further imply that factors influencing macroplastic pollution such as anthropogenic activities and waste management practices are similar in the areas.

Impacts of macroplastic litter in mangrove forest

The impacts of macroplastic litter on mangrove forests are extensive and complex, posing a serious threat to these vital ecosystems (Cordova 2021; Luo et al. 2022; Wang et al. 2023). Figure 7 illustrates the damage caused by plastic pollution on mangroves. Pneumatophores are crucial for mangrove tree respiration (Pallardy 2008), and plastic suffocating the root system that is smothered with plastic bags, bottles, and debris (Figures 7.A and 7.B) may significantly hinder their ability to exchange gases and acquire nutrients (Reef et al. 2010; Sundaramanickam et al. 2021; Moniuszko et al. 2023). Plastics in mangroves can also interfere with the respiratory function of mangrove roots, leading to reduced tree health and overall degradation of the mangrove ecosystem (Chai et al. 2023; Gunawardana et al. 2023). It can cause local scale anoxia in mangrove sediment, limit the growth of pneumatophores and propagules, and limit the growth of new saplings (Smith 2012; Selvam and Thamizoli 2021; Van Bijsterveldt et al. 2021). Moreover, the entanglement of plastic bags and fishing line around mangrove branches causes them to twist (Figure 7.C), and the resultant damage to the stem (Figure 7.D) disrupts the structure of the mangrove habitat that can cause physical damage leading to deterioration (Van Bijsterveldt et al. 2021; Liu et al. 2023).

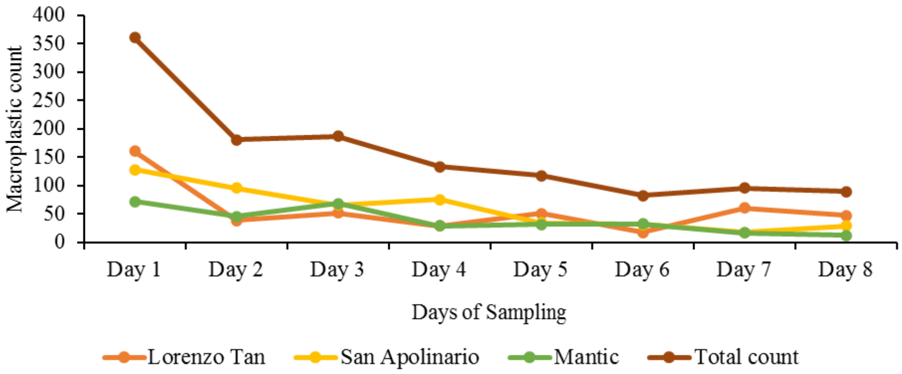

Figure 6. Quantity of plastic litter collected from three mangrove areas for eight non-consecutive days

Figure 7. Evidence of macroplastic litter found in all sampling sites in Tangub City, Philippines: smothering pneumatophores at A-B. Lorenzo Tan and San Apolinario, C. Twisted branches found at Lorenzo Tan, D. Damaged stem found at San Apolinario

Table 4. Macroplastic litter collected from different sites with density, Standard Deviation (SD) CCI analysis, and cleanliness rating

Site	Total litter count	Total area	Density	CCI	Cleanliness rating
Lorenzo Tan	459	2400	0.19±0.15	3.8	Clean
San Apolinario	480	2400	0.20±0.13	4	Clean
Mantic	311	2400	0.13±0.07	2.6	Clean

Table 5. One-way analysis of variance results for density between sites

Sampling sites	N	Mean	Sd	F-Value	Df	P-Value
San Apolinario	8	0.20	0.13	0.82	2, 21	0.45
Lorenzo Tan	8	0.19	0.14			
Mantic	8	0.13	0.07			

Several scientific studies support these findings, emphasizing the detrimental impact of macroplastic litter on mangrove ecosystems. The presence of plastics in the mangrove environment can cause prolonged anoxic conditions in the sediment, compromising the mangrove's overall health (Deng et al. 2023). A further investigation found that the constant entry of marine litter into mangroves can disrupt their natural conditions and harm the ecosystem, organisms, and humans (Vélez-Mendoza et al. 2022). These findings highlight the urgent need for waste reduction actions, such as education promotion, community involvement, and supportive policies (Paler et al. 2022), while emphasizing the significance of conducting studies on mangrove pollution to protect these vulnerable coastal ecosystems (Luo et al. 2021).

This study assessed the extent of macroplastic litter present in the mangrove forests across three barangays in Tangub City, Misamis Occidental, Philippines. The findings revealed that mangrove ecosystems act as natural filters, trapping plastic litter with varying efficiency depending on the mangrove species' composition. Food packaging, particularly those made of Low-Density Polyethylene (LDPE) polymer type, was the dominant type of litter collected, highlighting the influence of human activities on plastic pollution. Despite the cleanliness assessment rating all sites as "clean", the amount of plastic litter collected varied across sites. This suggests that both anthropogenic activities and waste management practices play significant roles in plastic distribution within the mangroves. Statistical analysis showed consistent plastic distribution across the studied areas and zones, indicating no significant differences across the mangrove forests. The study also emphasized the detrimental effects of macroplastic litter on mangrove forests, potentially disrupting vital ecological processes and leading to degradation. Understanding the extent and nature of plastic pollution in these critical coastal habitats is crucial for implementing effective management strategies and conservation efforts.

The study identified plastic pollution as a significant threat to mangrove ecosystems. Based on these findings, here are comprehensive recommendations for various stakeholders: (i) The findings of the study would like to recommend targeted educational campaigns as these are crucial to raising awareness about the negative impacts of plastic pollution on mangroves. These campaigns should be directed towards people living near these areas, such as coastal communities, fishermen, and tourists. Local media channels and educational materials can be used to spread information about responsible waste disposal practices and the importance of a healthy mangrove ecosystem. For instance, campaigns could utilize slogans and infographics in local languages to effectively communicate the dangers of plastic pollution. School programs and workshops can educate younger generations about responsible waste management and mangrove conservation, fostering a sense of environmental stewardship. Additionally, community outreach events can provide information and encourage participation in clean-up activities. (ii) To the community, the findings of this study would like to recommend organizing regular clean-up events in collaboration with local communities, academe, and environmental organizations. This fosters a sense of ownership for the health of the mangrove ecosystem while removing existing plastic debris. Partnering with schools can provide educational opportunities for students to understand the impact of plastic pollution. Citizen science initiatives can be incorporated into these events, allowing participants to collect valuable data on plastic pollution levels in mangroves. This data can be used for research and advocacy efforts to protect these vital ecosystems. (iii) This study also recommends improved waste management infrastructure as it is crucial to prevent further plastic pollution. Advocacy efforts should focus on implementing effective waste collection and disposal systems in areas surrounding mangroves. This could involve improved infrastructure for waste collection, establishment of recycling facilities, and development of composting programs. Policy changes that incentivize waste reduction and responsible waste management practices are also important. Pushing for bans on single-use plastics, extended producer responsibility programs, and increased funding for waste management initiatives can significantly contribute to a solution. (iv) Promoting the use of eco-friendly alternatives to single-use plastics is another key strategy. Encouraging the use of reusable bags, containers, and utensils can significantly reduce the amount of plastic entering the environment in the first place. Collaboration with businesses near mangroves can promote the availability and use of these sustainable options. (v) Lastly, the Barangay Local Government Unit (BLGU) in partnership with the DENR, should formulate localized policies and programs that address plastic pollution and protect the health of mangrove ecosystems.

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