Research Article

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Initial assessment of the presence of plastic waste in some coastal mangrove forests in Vietnam

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Abstract: Plastic, valued for its low cost and durability, is widely used in various aspects of daily life. However, accumulative plastic waste (PW) has emerged as an increasing environmental concern that causes a negative impact on both public well-being and marine biodiversity. Studies on marine PW have focused primarily on the number of PW items collected without considering its accumulation in coastal areas. Hence, this study aims to address this gap by meticulously examining the mass and constitution of macro PW in the summertime mangrove ecosystems of Hau Loc, Cat Ba, and Nha Trang. This study revealed that the average densities of PW collected in Hau Loc, Cat Ba, and Nha Trang mangrove forests were 0.93, 0.23, and 0.18 items·m^{-2} in the morning collection, whereas the afternoon collection showed slightly lower densities of 0.31, 0.12, and 0.14 items·m^{-2} for the same locations. Although all PWs in the standard plots were collected in the morning, PWs were present in the afternoon after the rising tide. This initially proves that tide is one of the reasons for increasing the presence of PW in mangroves. The most common types of PWs collected included water bottles, plastic bags, ropes, freight lines, fishing nets, and sponge floats. When assessing the PW composition based on mass, low-density polyethylene was the dominant PW category in Hau Loc with 5.97 g·m^{-2}. In Cat Ba, polypropylene was the highest with 11.87 g·m^{-2}, while polyethylene terephthalate was the highest with 0.9 g·m^{-2} in Nha Trang during the morning sampling. The "Others" type of PW was not present in any of the three locations. This study provides useful information that can be a foundation for future studies to analyze the relationship between socio-economic activities and the presence of PW in mangroves. Additionally, they hold the potential to guide the formulation of targeted strategies aimed at curbing plastic pollution within Vietnam's coastal regions.

Keywords: plastic waste, mangroves, item, composition, dimension

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1 Introduction

Plastic is a widely used material that offers numerous benefits due to its affordability, adaptability, lightweight nature, and durability. However, plastic pollution has become a major threat to the health of our oceans and wildlife. The inadequate waste management systems prevalent in many low- and middle-income countries have made them the primary source of global ocean plastic pollution. Plastic waste (PW) in the ocean is one of the most significant and pressing environmental challenges the world is facing today. According to Jambeck et al., out of the 275 million tons of plastics produced by 192 coastal countries, an estimated 4.8–12.7 million tons of PW end up in the ocean [1]. It is projected that global plastic production will reach 1,124 million tons by 2050 [2]. China, Indonesia, the Philippines, Vietnam, and Sri Lanka are the top five countries contributing to marine PW, generating a combined total of 17.34 million tons·per year, which accounts for almost 55% of the top 20 countries [2].

PW can have physical and chemical impacts on ecosystems and cause socio-economic impacts on local communities and regions. Physically, the presence of PW in the environment can affect biodiversity by trapping or killing organisms in the food chain. According to food and agriculture organization, plastics on the mudflats in mangroves impede the establishment of seeds and the growth of seedlings, resulting in negative effects on the mangrove ecosystem's services, economic activities, sustainable livelihoods, and the well-being of communities [3]. PW also reduces the habitats available to faunal groups [4]. Coastal birds, fishes, and other aquatic organisms are known to ingest plastic mistakenly as food [5]. More than 260 marine species have been recorded as entangled or having eaten plastic pieces in the sea, with an average of 2.1 pieces of plastic found in each fish in the North Pacific [6]. Chemically, research has demonstrated certain effects on aquatic organisms due to the sustainable existence of the constituent, fragmented compounds of PW. It is the intermediate component that transfers toxic pollutants from the environment into organisms. These substances enter the food chain and can potentially cause serious health effects [7]. In terms of socio-economics, PW directly impacts marine economic activities, causing losses in the cleaning of tourist beaches and navigable canals and affecting the tourist landscape. PW is also likely to cause injury or even be fatal to humans. United Nations Environment Programme reported that PW causes financial damage of US$13 billion to marine ecosystems each year as concern grows over microplastics [8]. Overall, the negative impacts of PW are extensive, affecting both the environment and the well-being of local communities.

The ecological and economic value of mangroves is well documented; however, substantial loss of this resource is occurring. Poverty among many coastal populations and opportunities for more sustainable livelihoods have led to the mismanagement of mangroves. However, the greater impact on loss has included the over-exploitation by conversion to alternative uses, including tourist resorts, agricultural use, industrial developments, and shrimp ponds. Mangrove forests offer a degree of resilience to climate change and increasing extreme weather events. They can significantly reduce the risk of coastal flooding from storm surges, and reduce the impact of typhoons and tsunamis. Mangroves have demonstrated considerable resilience over timescales commensurate with shoreline evolution. This notion is supported by evidence that soil accretion rates in mangrove forests are currently keeping pace with mean sea-level increases, offering further protection to coastal communities. The loss of mangrove standings can be felt more intensely by communities that have degraded them or removed them for more short-term gains, and marine plastic pollution has been recognized as having an increasingly detrimental effect on the viability of the mangroves. Poor waste management across many middle- and low-income countries means they dominate the sources of global ocean plastic pollution. Mangroves appear to be very efficient barriers against the redistribution of litter in the marine environment by wind and wave action and act as sink areas for collection.

Some scientists have studied PW in mangroves, but their studies have mainly focused on the accumulation of PW in mangroves and its negative effects on the development of mangroves [4,5,9,10]. However, there has been no assessment of the type and amount of macro PW trapped in mangrove forests based on size differences larger than 2 cm. Therefore, this study aims to determine the current status in terms of density and dimension of macro PW accumulated in mangrove forest floors to provide a database for further research and propose appropriate mitigation and management solutions, especially in the Cat Ba Biosphere Reserve and Nha Trang Bay Marine Reserve, which are known for their high diversity of ecosystems and developed tourism.

2 Methods

The research encompassed three distinct mangrove ecosystems in Vietnam. The first research site was situated in Phu Long commune, Cat Hai district of Hai Phong city, within the Cat Ba archipelago. This region is approximately 30 km east of Hai Phong city, bordering Ha Long Bay, and is renowned for tourism and aquaculture. The location is characterized by a typical diurnal regime, with tidal flats that are frequently exposed to the sun throughout the day when the tide recedes, due to the large fluctuation amplitude (reaching up to 3.8 m). The second research site was located in Da Loc commune, Hau Loc district of Thanh Hoa province, 25 km from the center of Thanh Hoa city. This mangrove forest is heavily influenced by local economic activities such as fishing, aquaculture, residential areas, and people's markets. The region is characterized by open sea, wide tidal flats, and a diurnal tidal regime. The third research site was situated about 7 km from the center of Nha Trang City, and its mangrove forest is mainly impacted by tourism activities. Similar to the previous sites, this location also experiences a diurnal tidal regime. The research was conducted in 2020, 2021, and 2022 in Hau Loc, Cat Ba, and Nha Trang, respectively.

To determine the amount of PW present in mangroves, we employed quadrat standards. Our investigation and experiments were focused on seven categories of plastic materials, which included polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and "Others" types. The classification was according to the classification code of the American Plastics Industry Association (SPI). This is the sorting required by recyclers in an effort to reduce the amount of waste in landfills. This study was carried out at three distinct mangrove locations, namely Cat Ba, Hai Hau, and Nha Trang, as shown in Figure 1. The location coordinates of quadrat standard plots are shown in Table 1. In each study area, three standard plots were randomly set up with an area of 100 m^2 (10 m × 10 m). The selected standard plots represent the areas near the mainland, intermediate, and low-lying coastal areas to determine the presence of the seven PW categories. The research process follows a five-step approach, as illustrated in Figure 2.

Step 1: Survey and selection of research sites

The research sites were carefully selected to avoid any direct influence from human activities such as tourism and livelihood every day. The locations within the mangrove forests that met these criteria were identified.

Step 2: Quadrat setup

Three quadrats were set up in each mangrove area with dimensions of 10 m × 10 m. The selected quadrat represents the mainland, intermediate, and low-lying coastal areas. In each area, three quadrats were set up. The quadrats were spaced 100 m apart, and bamboo sticks were used to mark each quadrat for the following sample collection.

Step 3: Collection and weighing of PW

Sampling frequency is based on the Guidelines on "Methods of monitoring PW at sea including riverine and marine monitoring" under the project "BLASTIC – Plastic waste pathways into the Baltic Sea, SEI" [11]. After setting up standard quadrats, all PWs with a size >2 cm in each quadrat on the mangrove tree, floor, and ground up to 50 cm depth were collected. The sampling frequency was 2 times·day^{-1}. Sampling time was at 6:00 AM and 6:00 PM on the same day to evaluate the presence of PW under the influence of tides. Thus, the total number of samples in each mangrove forest is 3 quadrats × 3 areas × 2 times·day^{-1}, which is 18 samples.

Table 1: The location coordinates of quadrat standard plots

No.	Research locations	Latitude	Longitude
1	Cat Ba	20°80′43.84″N	106°93′98.06″E
2	Hau Loc	19°56′36.59″N	105°59′10.59″E
3	Nha Trang	12°12′22.183″N	109°12′5.289″E

Step 4: Sorting and categorizing of PW

The PW collected was sorted into seven groups, which included PET (plastic bottles, plastic trays, food packaging, etc.), HDPE (detergent bottles, shampoo, etc.), PVC (toys, broken water pine), LDPE (Vietnamese nylon bags, food packaging, lunch box, etc.), PP (bottle caps, yogurt boxes), PS (plastic utensils, single-use plastic, etc.), and "Others."

Step 5: After being classified, each collected sample was counted and weighed, and the dimensions were measured.

The average distribution volume and mass percentage of each type of PW are calculated according to formulas 1 and 2:

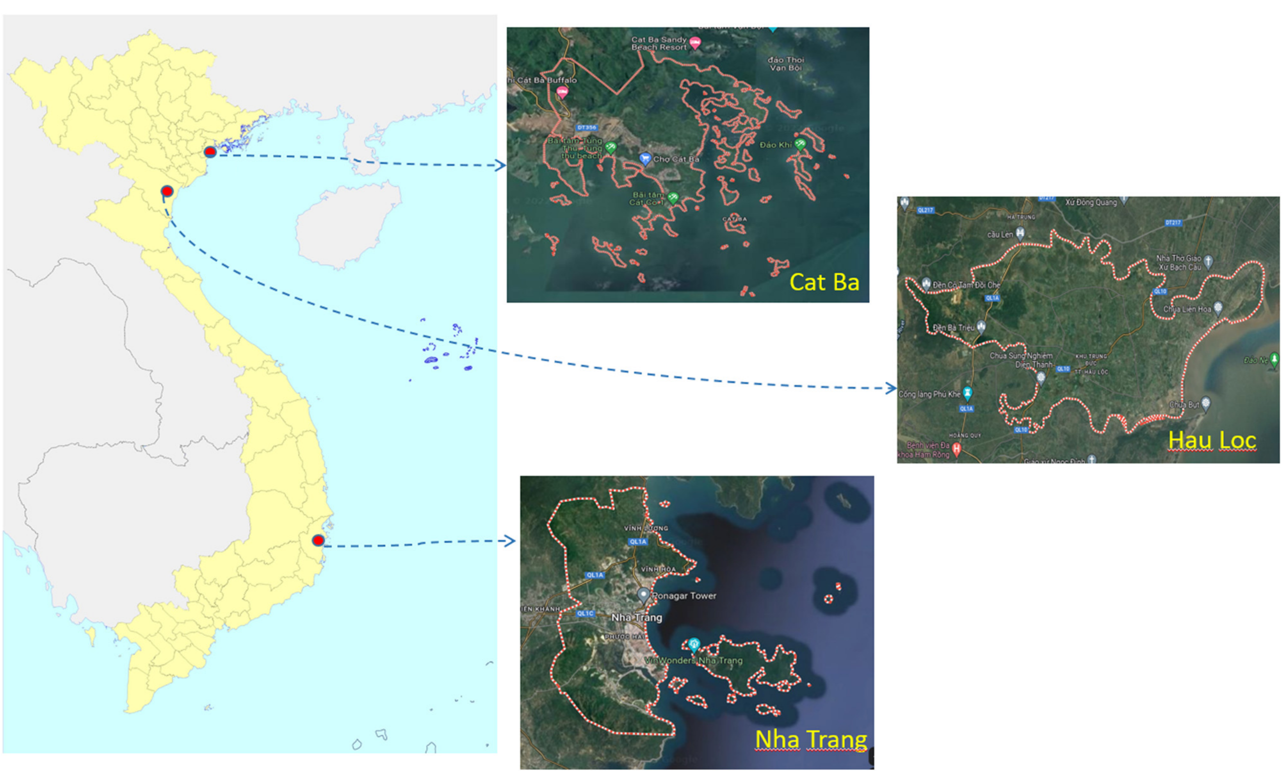

Figure 1: Research locations.

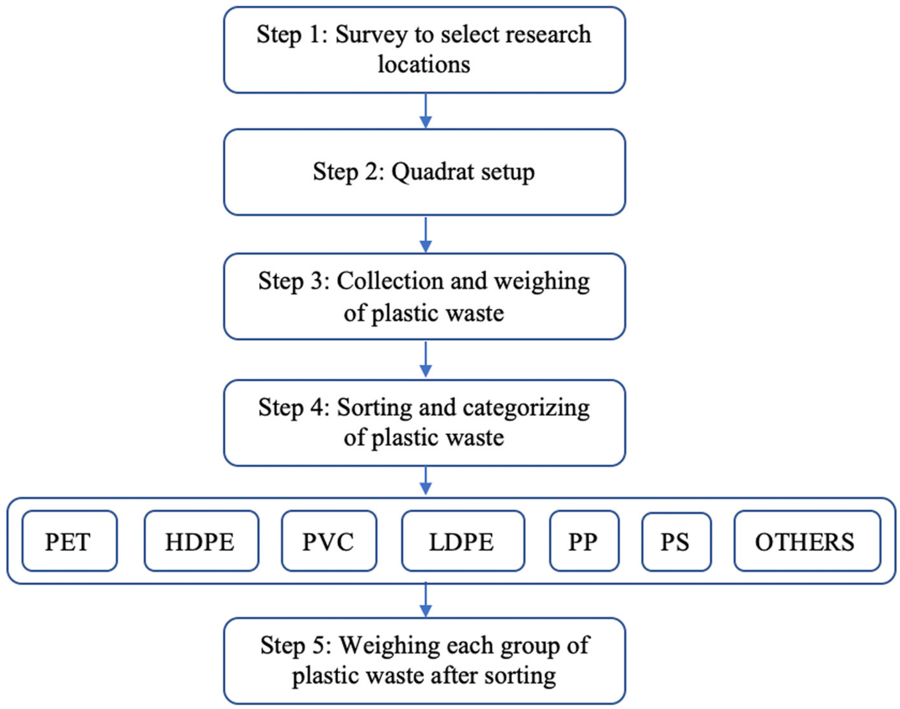

Figure 2: Research process diagram.

$$\text{Average distribution volume} = \frac{M}{300}(\text{g/m}^2) \quad (1)$$

$$\text{Mass percentage} = \frac{m}{M} \times 100(\%) \quad (2)$$

where M (g) is the total volume of PW collected in all three quadrats and m (g) is the volume of each kind of PW.

3 Results and discussion

3.1 Quantity and dimension by type of PW in the study areas

The presence and dimension of each type of PW in the study areas are presented in Tables 2 and 3.

Table 2 presents the item count of 6 out of 7 types of PW collected across the three designated study areas. A comparative analysis of morning and afternoon collections in Cat Ba, Hau Loc, and Nha Trang reveals the following patterns: in Cat Ba, a total of 73 items were gathered during the morning, corresponding to an average density of 0.24 items·m^{-2}. The distribution of PW types exhibited a semblance of similarity, with PP (28 items), LDPE (20 items), HDPE (10 items), and PET (9 items). Conversely, in the afternoon collection, the total number of PW items collected was 35 items, resulting in an average density of 0.12 items·m^{-2}, a decrease of 52% compared to the morning. The PP (15 items) and LDPE (11 items) retained their dominance. The average size of PW collected ranges from 5.2 ± 3.1 to 17.6 ± 18.1 cm in width and 5.8 ± 4.3 to 35 ± 13.7 cm in length (Table 3). PS and "Others" were not found in Cat Ba. The findings from the survey indicated that the Cat Ba mangrove forest may not be significantly impacted by local human activities. Furthermore, upon comparing with the Hau Loc mangrove forest, it was evident that the PW density in Cat Ba was almost four times lower. These differences in PW accumulation could potentially be attributed to variations in tidal flat features, the density of forest trees, and the origins of PW generation within the study vicinity.

In the Hau Loc mangrove forest, a total of 276 PW items were collected in the morning, resulting in an average density of 0.93 items·m^{-2}. The most dominant type was LDPE, accounting for 175 items and making up 63.4% of the total. These items were primarily plastic bags and food packaging, typical components of PW stemming from local activities like fish markets and daily life. The second-largest category was PP, with 84 items constituting 30.4% of the total. These items mainly included ropes, lines, fragments of fishing nets, and torn bags, which are outcomes of fishing and aquaculture activities. PS had the third largest number of collected samples with ten items, and the main items were buoys and

Table 2: Number of PW items in the three study areas

No.	Types of PW	Cat Ba (item)		Hau Loc (item)		Nha Trang (item)		Total (items)
		Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	
1	PET	9	2	6	8	13	11	**49**
2	HDPE	10	2	0	0	7	5	**24**
3	PVC	6	3	3	1	0	0	**13**
4	LDPE	20	11	173	42	11	9	**266**
5	PP	28	15	84	25	2	0	**154**
6	PS	0	2	10	16	22	17	**67**
7	Others	0	0	0	0	0	0	**0**
Total (item)		**73**	**73**	**35**	**276**	**92**	**55**	**42**

foam pieces. Only six items of PET were collected including plastic water bottles and pieces of clothing. PVC had the least number of items with only three, and these were mainly water bottle labels. In the afternoon collection, LDPE and PP remained the primary types of PW encountered. Notably, PS increased by 60% compared to the amount collected in the morning, mainly consisting of plastic bags entangled in mangrove trees due to tidal influence. The HDPE and "Other" PWs, however, were absent in the Hau Loc mangroves. The dimensions of PW in Hau Loc varied, ranging from 3.4 ± 3.1 to 28.8 ± 22.4 cm in width and from 7.5 ± 4 to 118.2 ± 112.8 cm in length. Additionally, the longest PW item collected in Hau Loc was PP, while the widest was LDPE.

In Nha Trang, various types of PWs were identified, including PET, PS, PP, LDPE, and HDPE, as indicated in Table 2. During the morning collection, a total of 55 items were gathered, resulting in an average density of 0.18 items·m^{-2}. Among these, PS constituted the highest number with 22 items, primarily encompassing bottle caps and diverse forms of food packaging. PET accounted for 13 items, mainly comprising water bottles. LDPE contributed 11 items, including primarily flexible bottles and caps, and a small number of electrical wires. HDPE represented 7 items by fruit and probiotic yogurt containers. On the other hand, only two items of PP were collected. In the afternoon, the total amount of collected PW was reduced by 20% compared to the morning but the dominant PW remained unchanged. The results showed that PS, PET, and LDPE were predominant in Nha Trang, a region that mainly impacted tourism activities that lacked proper waste collection and management. Nha Trang exhibited the lowest quantity of PW items collected. This leads to the initial conclusion that the presence of PW in mangroves is influenced not solely by tides, but also by socio-economic conditions and the availability of effective collection and disposal methods. These factors will be comprehensively examined in subsequent studies by the same authors.

Among the six types of plastic found in mangroves, LDPE emerges as the prevailing component of PW (Figure 3). This category includes plastic bags, straws, bottles, food wrappers, and food containers. Despite the prevalence of these plastic items, plastic bags remain the most commonly found type. HDPE-based PW is predominantly gathered by

Table 3: Dimensions of collected PW items in the three study areas

No.	Types of PWs	Cat Ba				Hau Loc				Nha Trang			
		Width range (cm)		Length range (cm)		Width range (cm)		Length range (cm)		Width range (cm)		Length range (cm)	
1	PET	2	7	3	21	2	20	13	80	6	13	21	35
2	HDPE	6	13	3	18	nd	nd	nd	nd	2	11	12	16
3	PVC	9	15	10	34	9	15	10	34	nd	nd	nd	nd
4	LDPE	7	4	11	26	2	65	3	150	10	3	3	9
5	PP	2	49	2	76	2	35	5.5	300	3	26	32	36
6	PS	nd	nd	nd	nd	2	9	6	27	4.5	12	8	13
Average		**5.2**	**17.6**	**5.8**	**35**	**3.4**	**28.8**	**7.5**	**118.2**	**5.1**	**13**	**15.2**	**21.8**
Standard deviation		**3.1**	**18.1**	**4.3**	**23.7**	**3.1**	**22.4**	**4.0**	**112.8**	**3.1**	**8.3**	**11.5**	**12.8**

Note: nd – Not detected.

waste collectors and then procured by local micro-enterprises in craft villages. However, a substantial portion of HDPE PW remains unsorted, uncollected, unreprocessed, or improperly disposed of. While hard plastic bottles can undergo recycling processes to transform into other products, plastic bags, and food wraps are often neglected in terms of collection and recycling efforts. Hence, the imperative lies in implementing pertinent measures to promote reuse, efficient collection, and proper disposal of PW. These actions are paramount in curtailing their presence within the environment, particularly within sensitive ecosystems like mangrove forests.

3.2 Mass of macro PW present in mangroves

The results herein showed that the Hau Loc mangrove forest exhibited an average PW mass of 14.64 $g \cdot m^{-2}$. This waste possibly originates from marine sources, drifting onto the coastline and subsequently trapped within the intricacies of mangrove branches and roots. The most abundant plastic type by weight·m^{-2} is LDPE, with an average of 5.97 $g \cdot m^{-2}$. PP follows with an average of 4.76 $g \cdot m^{-2}$, while PVC has the third largest average volume of 2.54 $g \cdot m^{-2}$. PS has an average of 0.79 $g \cdot m^{-2}$, while PET has 0.57 $g \cdot m^{-2}$. Among the various types of collected PW, PP was the highest with an average weight of 11.87 $g \cdot m^{-2}$. PVC followed closely with an average weight of 5.37 $g \cdot m^{-2}$, followed by HDPE of 0.55 $g \cdot m^{-2}$. PET, LDPE, and PS had average weights of 0.47, 0.36, and 0.22 $g \cdot m^{-2}$, respectively. This study did not detect polycarbonate (PC) waste, which often contains BPA and is considered unsafe due to its carcinogenic attributes. In Nha Trang, PET exhibited the highest weight with 0.9 $g \cdot m^{-2}$, followed by PS at 0.7 $g \cdot m^{-2}$. HDPE, LDPE, and PP were collected with weights of 2.5, 1.5, and 1 $g \cdot m^{-2}$, respectively. These variations could be attributed to diverse factors, including the amount of PW generated in the area, the efficacy of PW management practices, and the proximity of the mangrove to sources of PW.

These findings offer valuable insights into the prevalent PW varieties within the Nha Trang mangrove area, a region primed for year-round sea tourism. Notably, PET waste originating from bottled water represents the most frequent type. Gaining a comprehensive understanding of the PW composition in this locale holds the potential to facilitate the formulation of precise approaches for tackling plastic pollution. For instance, given PET's dominance in the waste stream, it becomes feasible to devise planning focusing on reducing PET waste, enhancing recycling initiatives, and optimizing waste management practices. When comparing the results of the research conducted in Cat Ba, Hau Loc, and Nha Trang, it was found that the total mass of macro PW was highest in Nha Trang, with 21 $g \cdot m^{-2}$. Cat Ba had the second-highest total mass with 18.48 $g \cdot m^{-2}$, while Hau Loc exhibited the lowest total mass of 14.64 $g \cdot m^{-2}$. In terms of plastic types collected across these study areas, PET emerged as the most frequently encountered macro plastic, achieving the highest weight·m^{-2} in Nha Trang with 0.9 $g \cdot m^{-2}$. Meanwhile, PP dominated as the most commonly collected plastic in Cat Ba and Hau Loc, with respective weights·m^{-2} of 11.87 and 5.97 $g \cdot m^{-2}$.

Regarding specific plastic categories, LDPE emerged as the dominant plastic-type in Hau Loc, whereas PVC held the second-most prominent position in both Hau Loc and

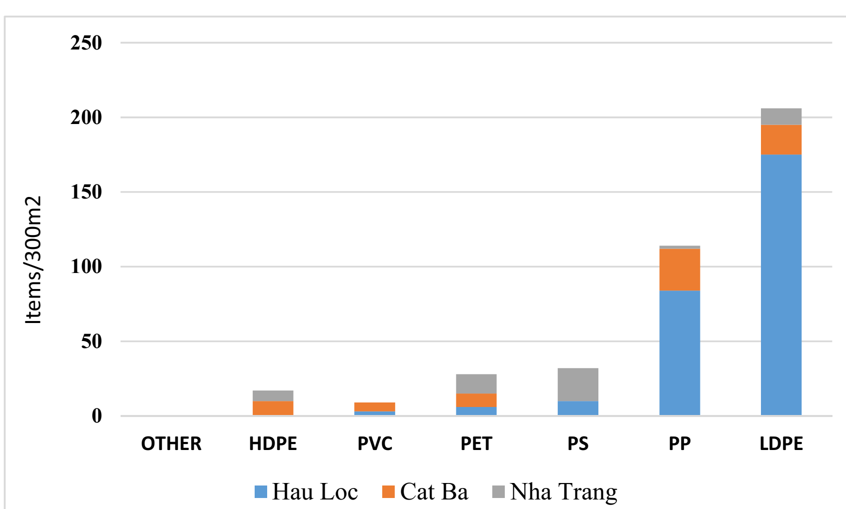

Figure 3: Total items by composition in the three study areas in the morning collection.

Cat Ba. Notably, the “Others” plastic category, which includes PC and is deemed carcinogenic due to its BPA content, was conspicuously absent in all three study areas. Taken together, these findings underline the pressing necessity for well-suited interventions aimed at reducing the presence of macro PW within mangrove ecosystems. This need is particularly pronounced in regions where the total waste mass is higher, highlighting the importance of tailored strategies to address varying levels of PW impact.

In terms of the types of plastics found in mangrove forests, research results are consistent with other research studies, which have also found that LDPE, PP, and PVC are commonly present in marine and coastal environments. For instance, a study conducted in the coastal waters of Ghana found that PP and LDPE were the most commonly collected plastics [12], while another study conducted in a beach in Spain found that PVC was the third-most commonly found plastic after PET and HDPE [13]. A study conducted on a beach in Greece found that PS was the third-most commonly found plastic after PP and PET [14]. The current study also identifies common items such as plastic bags, straws, bottles, food wrappers, and containers, which echo findings from previous research. However, other studies have found that fishing gear, such as nets and lines, can also be a significant source of plastic pollution in marine and coastal environments. For example, a study conducted in the Mediterranean Sea found that fishing gear accounted for 44% of the total weight of PW collected [15]. Therefore, this study highlights the importance of understanding the sources and pathways of plastic pollution in mangrove forests that PW was primarily generated by nearby human settlements, and that mangrove litter traps were a major sink for this waste. Understanding the sources and pathways of plastic pollution can help to identify effective strategies for reducing its impact on these ecosystems.

4 Conclusion

The study on macro PW in mangrove forests provides important insights into the composition and mass of PW in these important ecosystems. The densities of PW in mangrove forests in Hau Loc, Cat Ba, and Nha Trang were found to be 0.93, 0.24, and 0.18 items·m^{-2} in the morning and 0.31, 0.12, and 0.14 items·m^{-2} in the afternoon, respectively. The most commonly found PW items were water bottles, plastic bags, ropes, freight lines, fishing nets, and sponge floats. The studies found that LDPE, PP, and PVC were the most commonly found plastics in mangrove forests in Vietnam, with PET and PS also present but in smaller quantities. In terms of mass-based composition, LDPE was found to be the dominant PW component in Hau Loc, while PP was dominant in Cat Ba, and PET was the most commonly found in Nha Trang. Interestingly, the “Others” type of plastic was not found in any of the research locations. The findings of these studies are consistent with other research studies on plastic pollution in marine and coastal environments, highlighting the urgent need for action to address this global environmental problem. These findings suggest that the diversity of economic activities in the Hau Loc area may lead to a higher accumulation of macro PW, both in terms of mass and number of items, compared to Cat Ba and Nha Trang, which are primarily affected by tourism and aquaculture activities. Overall, this study initially provides information on the presence of PW in mangroves under the influence of tides during the day. The relationship between PW presence and generation, economic, social, and environmental characteristics including collection and recycling systems and public perception regarding PW will be evaluated in future studies.

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Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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