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Plastic waste in sandy beaches and surface water in Thanh Hoa, Vietnam: abundance, characterization, and sources

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Abstract The occurrence and characterization of marine debris on beaches bring opportunities to track back the anthropogenic activities around shorelines as well as aid in waste management and control. In this study, the three largest beaches in Thanh Hoa (Vietnam) were examined for plastic waste, including macroplastics (≥ 5 mm) on sandy beaches and microplastics (MPs) (< 5 mm) in surface water. Among 3803 items collected on the beaches, plastic waste accounted for more than 98%. The majority of the plastic wastes found on these beaches were derived from fishing boats and food preservation foam packaging. The FT-IR data indicated that the macroplastics comprised 77% polystyrene, 17% polypropylene, and 6% high-density polyethylene, while MPs discovered in surface water included other forms of plastics such as polyethylene- acrylate, styrene/butadiene rubber gasket, ethylene/propylene copolymer, and zein purified. FT-IR data demonstrated that MPs might also be originated from automobile tire wear, the air, and skincare products, besides being degraded from macroplastics. The highest abundance of MPs was 44.1 items/m^3 at Hai Tien beach, while the lowest was 15.5 items/m^3 at Sam Son beach. The results showed that fragment form was the most frequent MP shape, accounting for 61.4 ± 14.3% of total MPs. MPs with a diameter smaller than 500 μm accounted for 70.2 ± 7.6% of all MPs. According to our research, MPs were transformed, transported, and accumulated due to anthropogenic activities and environmental processes. This study provided a comprehensive knowledge of plastic waste, essential in devising long-term development strategies in these locations.

Keywords Microplastics · Plastics waste · Marine debris · Vietnam · Sandy beach

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Introduction

Marine debris is described as abandoned artificial artifacts which may be found practically anywhere in the marine environment (Gall & Thompson, 2015; Ryan, 2015). Marine debris can even be found in archipelagos, the seafloor, and the polar zones (Enrichetti et al., 2020; Garcés-Ordóñez et al., 2020; Kaviarasan et al., 2020; Mulochau et al., 2020). The composition of marine debris is quite diverse, arising from items used in anthropogenic activities in which plastic waste accounts for about 70% of total marine debris (Vlachogianni et al., 2018; Zablotski & Kraak, 2019) or reaches up to 89% of the volume in the Wusta Governorate Wetland Nature Reserve in Oman (van Hoytema et al., 2020). Plastic waste (particularly microplastics (MPs)) has a negative impact on the environment, ecosystems, and marine organisms due to their poor biodegradability and capability to adsorb hazardous organic chemicals such as persistent organic pollutants, polycyclic aromatic hydrocarbons, organochlorine insecticides, heavy metals, and antibiotic compounds (Frias et al., 2010; Jiménez-Skrzypek et al., 2021). These pollutants can impair ecosystem function (Ahmad et al., 2020; D'Alessandro et al., 2018; Kang et al., 2015a, b; Renzi et al., 2018; Tien et al., 2020) and have an impact on human health via the food chain (Sigler, 2014; Smith et al., 2018).

Recent research has identified MPs in the earth's polar ice layers (Ivar Do Sul et al., 2014; Joana et al., 2021; Kanhai et al., 2018; Mishra et al., 2021) as well as in some of the most pristine ecosystems, such as glaciers on the Tibetan Plateau in China (Y. Zhang et al., 2021). MPs are found in a variety of environments, including drinking water, sediments, coastal estuaries, offshore oceans (Almaiman et al., 2021; Jiang et al., 2020; Schröder et al., 2021; Suteja et al., 2021; Zhang et al., 2017), and coral reefs (Huang et al., 2019; Nie et al., 2019). The MP emission sources depend on the climatic circumstances – meteorological, hydrology, and socio-economic factors, namely, wastewater treatment facilities, home wastewater, landfill leakages, ocean currents, human activities at sea such as fishing, oil drilling, tourism, or coastal activities (Cole et al., 2011; Faruk Çullu et al., 2021; Freeman et al., 2020). For example, some studies indicated that the marine debris was formed deep inside the continent, originating in estuaries and from human activities in coastal towns (Binetti et al., 2020; Ertaş, 2021). The study by Rangel-Buitrago et al. (2021) agreed that, on some distant Colombian Caribbean Sea islands, plastic waste is generated by anthropogenic activities (Rangel-Buitrago et al., 2021). Beaches in French Polynesia are classified as "dirty," and the majority of marine litter originates on the mainland, including 43% of waste from the mainland, 17% from tourism activities, 15% from inshore fishing activities, 8% from marine life, and 8% from large offshore vessels (Verlis & Wilson, 2020). On the other hand, Veerasingam et al. (2020) concluded that marine debris in the studied location is mostly determined by wind and flow variables with a density of 1.98 items/m^2 (Veerasingam et al., 2020). An investigation in the Mediterranean Sea at a depth of 250–400 m reported a rubbish density of 4.63 items/100m^2 in relation to the rise in marine litter from discarded fishing gear. Approximately half of the floating waste gathers on the river's beaches, with the other half flowing towards the sea due to the Stokes drift (Korshenko et al., 2020).

According to the research above, the occurrence of plastics waste or MPs can be used to trace back to human activities on the continent or at sea, such as abandoned fishing gear thrown at sea, service operations on the shore, sports and entertainment activities, and drifting to surrounding locations. Plastic wastes will have distinct characteristics in each location and must be individually studied in order to develop strategies to avoid and decrease pollution causes.

When assessing anticipated inputs of unmanaged plastic garbage within 50 km of coasts, Vietnam is among the top five nations in the world for post-consumption plastics pouring into the oceans (Kerber & Kramm, 2022). Surprisingly, only a few studies have investigated plastic pollution along Vietnam's shores (Duong et al., 2020; Tran Nguyen et al., 2020; Truong et al., 2020). As a result of the adverse effects of plastic pollution, a pilot study along Vietnam's coast is required to serve both local and international interests. In this study, macroplastics in three sandy beaches in Thanh Hoa province, Vietnam (i.e., Hai Hoa beach, Hai Tien beach, and Sam Son beach), were examined. The physical and chemical characteristics of macroplastics have been thoroughly investigated by using Fourier transform infrared (FTIR) measurements. Besides, the abundance, colors, sizes, and shapes of MPs in the surface water were studied.

To illustrate the visible plastic pollution, we took representative photos (Fig. 1) at the three beaches.

Methodology

Sampling

Samples from three different sandy beaches along the coast of Thanh Hoa, Vietnam (i.e., Hai Hoa beach, Hai Tien beach, and Sam Son beach) were collected. Thanh Hoa is a province in the North Central Region, with geographical coordinates of 19°23′–20°30′ northern latitude and 104°23′–106°30′ eastern longitude. The total area accounts for 3.37% of the entire natural area of Vietnam. The sampling locations are shown in Fig. 2. These beaches exhibit distinct forms of human effect on the beach, detailedly described in the Supplementary (Section S1). Sampling locations were chosen to ensure consistency for future sample occasions related to monitoring plastic waste. Thanh Hoa province has particular environmental features that might affect the presence or concentration of plastics, such as fast tourism development, an important aquaculture area in northern (150 km south of Hanoi capital), and rapid urbanization. Three beaches in this study cover 102 km of Thanh Hoa coast, which makes the total sampling area about 20 km^2. Besides, each beach also represents a distinct characteristic. For example, Hai Tien beach is the most well-known and populated location. In comparison to two other beaches, Hai Hoa beach remains comparatively pristine.

Fig. 1 Representative photos of the three studied beaches. **A** Sam Son Beach has a rich history of tourist development. **B** The public sanitation activity daily occurs from 5 a.m. until 7 a.m. at Sam Son beach. **C** Hai Hoa beach is the most pristine of the three studied beaches. **D** A sample of a fishing boat that is made from foam materials. They are commonly used at the Hai Hoa beach. **E** and **F** Example of plastic pollution at Hai Tien beach. The Hai Tien beach has been embanked with solid concrete, and tourism activities are quite active

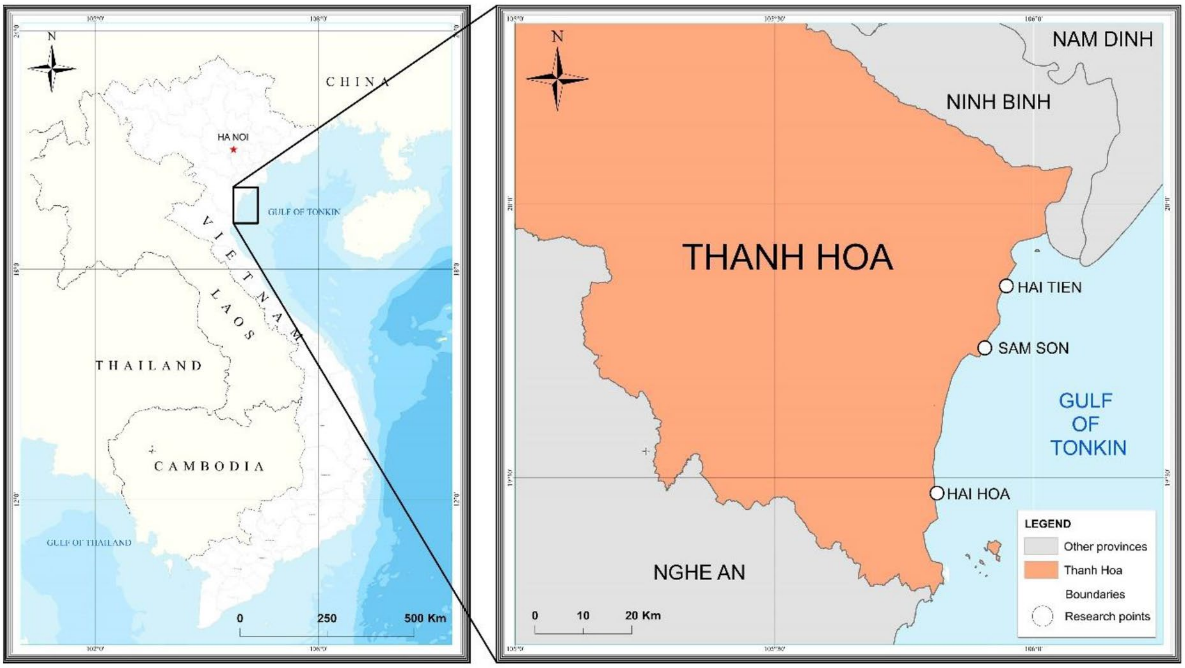


Fig. 2 Maps showing the sampling locations

Collecting samples from sandy beaches

Regarding macroplastics, samples were obtained for the first time from March 24 to 29, 2020, when tourists were inactive. The second time period was chosen from July 15 to July 20, 2020, during a period of significant tourist activity. The sampling periods were also selected based on the precipitation of the sampling location. From 1995 to 2020, the average rainfall at Thanh Hoa province's monitoring station in March and July was 43 mm and 200 mm, respectively (General Statistics Office of Vietnam, 2021). As a result, in Thanh Hoa province, March corresponds to the dry season and July to the wet season. Every day throughout the sample period, starting at 4h30 a.m. (before the cleaning operations begin; see Fig. 1), marine debris was collected on beaches. Depending on the topography and weather circumstances, 4–8 samples were taken on each beach. The sampling procedures used were in accordance with the Guidelines for Marine Debris Survey and Monitoring (Alkalay et al., 2007; Anthony & Ellik, 2009). Briefly, a 10-m coastline was drawn out and split into 2-m sections for sampling. Each 2-m section represents the area along each transect from the water's edge to the back of the beach (Fig. 3). All waste kinds with dimensions (≥ 5 mm) were collected at each sample unit. Then, macroplastics were manually separated from the other types for further analysis (Lim et al., 2021).

Collecting microplastics from surface water

The MP samples were obtained using the net towing method (Ryan et al., 2009), with a horizontal tow net (50-cm diameter, 150-cm length, 80-µm Dolphin™ bucket, Wildco®) with an attached mechanical flow meter (General Oceanics® Model 2030R) to measure water volume sampled (Fig. 4). MP samples were gathered using a net, transferred to a 500-ml brown sandblasting bottle, kept at 4 °C, and then sent to the laboratory for further testing (Bujaczek et al., 2021; Driscoll et al., 2021).

Quality assurance (QA) and quality control (QC)

Quality control and assurance measures are implemented to avoid plastic contamination from sample collection and MP determination in the laboratory.

Samples were collected and passed through 5-mm and 1-mm stainless steel sieves. The sieved

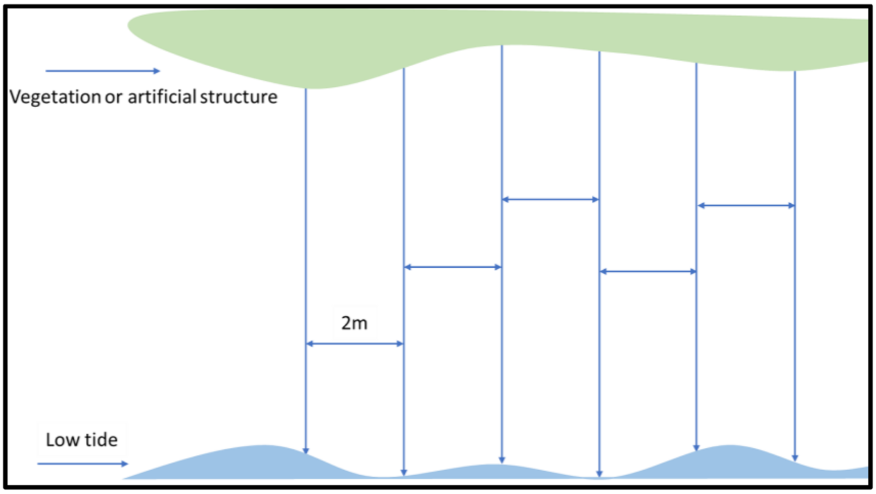


Fig. 3 Sampling design displaying perpendicular transects from the water's edge extends to the back, eventually reaching the first barrier (e.g., vegetation, artificial structures)

fraction was then transferred to a 1000-mL colored glass flask, rinsing the bottom of the beaker with distilled water to ensure that the microplastics were completely transferred to the beaker. Blanks are performed in parallel, using distilled water, similar to the process of transferring the sample from the mesh through the sieve to the glass flask.

In the laboratory, samples are processed in glass beakers, and aluminum foil is used to cover the mouth of the cup during processing. All laboratory instruments used for MP's determination were glass and stainless steel. The blank is paralleled with the actual sample to control for contamination, if any, from the environment (Scopetani et al., 2019).

Analytical method

Microplastic pretreatment and density separation

After being transported to the laboratory, materials were filtered using stainless steel sieves with mesh sizes of 5 mm and 1 mm. The particles bigger than 5 mm were discarded, while the remaining particles on the 1-mm sieve were rinsed with distilled water, collected in a petri dish, and dried for 24 h at 50 °C (J. Masura et al., 2015; Pico et al., 2019).

All particles that passed through the 1-mm sieve were transferred to a 1000-ml beaker and evaporated in a 90 °C water bath. Allow the beaker to dry and

Fig. 4 Wildco net with an 80-µm mesh size was used to collect microplastics in surface water. The associated flowmeter can calculate the amount of water that enters the net. The water quality was further discussed in the Supplementary (Section S2)

cool to room temperature before adding 20 ml of 0.05 M Fe(II) solution (7.5 g $FeSO_4.7H_2O$ was added to 500-mL distilled water containing 3-mL concentrated H_2SO_4 to make the solution) (Masura et al., 2015). To eliminate organic matter interference, 20 mL of 30% H_2O_2 was added to the beaker containing the water sample, the combination was vigorously vibrated, and the mixture was left at room temperature for 5 min to allow the breakdown reaction to take place. The mixture was then cooked for 30 min in a water bath at 75 °C. If the organic waste dissolved incompletely, add another 20 mL of 30% H_2O_2, and restart the procedure (Masura et al., 2015).

To enhance the density of the solution, add 6.0 g of NaCl salt per 20 ml of sample (Kapukotuwa et al., 2022; Masura et al., 2015). To thoroughly dissolve the salt, the mixture was boiled in a water bath at 75 °C. The whole thing was then poured into a density funnel. The funnel was allowed to settle overnight (or 12 h); clamping in the density funnel was used to visually verify if the solids had settled and separated; settled particles were eliminated. Collect the supernatant in a beaker, then rinse the sample in the density funnel, and transfer it to a glass flask. Transfer the solution to a Whatman vacuum filter and filter it through a 0.45-μm cellulose acetate membrane before rinsing the filter funnel with distilled water. Place the membrane filter in a Petri dish, and dry for 24 h at 50 °C (Duong et al., 2022; Kapukotuwa et al., 2022).

Classification of macroplastics

In general, marine debris is classified according to material properties (Anthony & Ellik, 2009), including plastics, metal, glass, paper, rubber, cloth, wood, and ceramics. In this study, macroplastics were classified as items, including food covers (e.g., candy, snacks, drinks, cups, others), plastic bags, styrofoam (e.g., sponge, food packaging foam, foam buoy, foam insulation, others), fishing gear (e.g., fishing nets, traps), and some other form.

Determine the abundance, shape, color, and size of microplastics

For MPs on the 1-mm sieve, the size of particles was determined by a ruler, while color and shape were determined by direct observation. MPs with a diameter of less than 1 mm, on the filter membrane, are observed with a Leica S9i stereo microscope with a magnification of 6.1×-55x; MP items are counted, measured, and observed by image analysis stools (LAS-X images). The size of the MPs is divided into four classes as follows: 100–500 μm, 500–1000 μm, 1000–2000 μm, and 2000–5000 μm. MPs were categorized following the recommendation of UNEP (Peter et al., 2019). Briefly, the MP shape was classified into three types, including pellets, fragments (i.e., fragments, film, foam), and fibers. The color of microplastics is identified through some of the following basic colors: blue, yellow, red, purple, black, and white (Frias et al., 2018).

Chemical properties of plastic waste

MPs after the separation step (Sect. "Microplastic pretreatment and density separation") and macroplastics were analyzed using Fourier transform infrared (FTIR) measurements (Frias et al., 2018; Kim et al., 2018; Napper et al., 2021). The obtained infrared spectrum was then compared with those available in the library to determine the type of plastics. In this study, an Agilent's FTIR Carry 630 spectrometer and the universal library Agilent Polymer Handheld ATR Library were used.

Results and discussions

Properties of macroplastics at beaches

For better visualization, some photos of macroplastics in the region were presented (Fig. 5). Figure 5 shows that the source of macroplastics on these beaches was mainly anthropogenic activities.

As can be seen in Table 1, the largest component of macroplastics on beaches is foam (70.2 ± 18%, $n = 35$), which originates from foam containers that hold food from locals and visitors. Furthermore, the usage of foam in the making of fishing boats has been recognized as the primary source of foam waste on the province's beaches (Fig. 1, Section S3). As reported, fishers frequently utilize styrofoam as buoyancy material for boats. These foams are mostly formed of polystyrene, which decomposes easily in the environment to produce a large number of pieces (Terzi et al., 2020).

Fig. 5 Representative macroplastics found on the studied beaches. Various plastic items were found (from March to July 2020), including fishing items and waste from visitors on the beach. Various types of macroplastics, namely, styrofoam debris, fishing net, rope, confectionery cases, plastic bags, disposable cups, beverage bottle caps, disposable straws, snack bags, cigarette packs, milk cartons, and hair ties

In this study, the scan range was from 4000 to 650 cm^{-1} (Fig. 6). The polymer types of the MPs were selected from the Agilent Micro Lab FTIR software library, and the best quality result was chosen. If the hit quality reached lower than 70%, we matched the measured spectrum to the library's and determined the polymer kinds based on the look and shape of the fragments (Yukioka et al., 2020).

The results show that 77% of macroplastics were polystyrene (PS), 17% were high-density polyethylene (HDPE), and only 6% were polypropylene (PP). These

Table 1 Macroplastic composition by item classification in 2020

Macroplastics type	Hai Tien Beach		Sam Son Beach		Hai Hoa Beach	
	Mar, $n=8$	Jul, $n=6$	Mar, $n=6$	Jul, $n=4$	Mar, $n=6$	Jul, $n=5$
Styrofoam (%)	81.7	48.4	62.9	56.0	85.9	85.0
Bags (%)	5.8	5.3	7.5	7.0	3.9	3.6
Food covers (%)	5.0	41.8	8.6	22.7	7.6	9.1
Fishing gear (%)	5.8	1.3	16.4	11.4	0.2	0.2
Others (%)	1.7	3.1	4.7	2.9	2.4	2.1

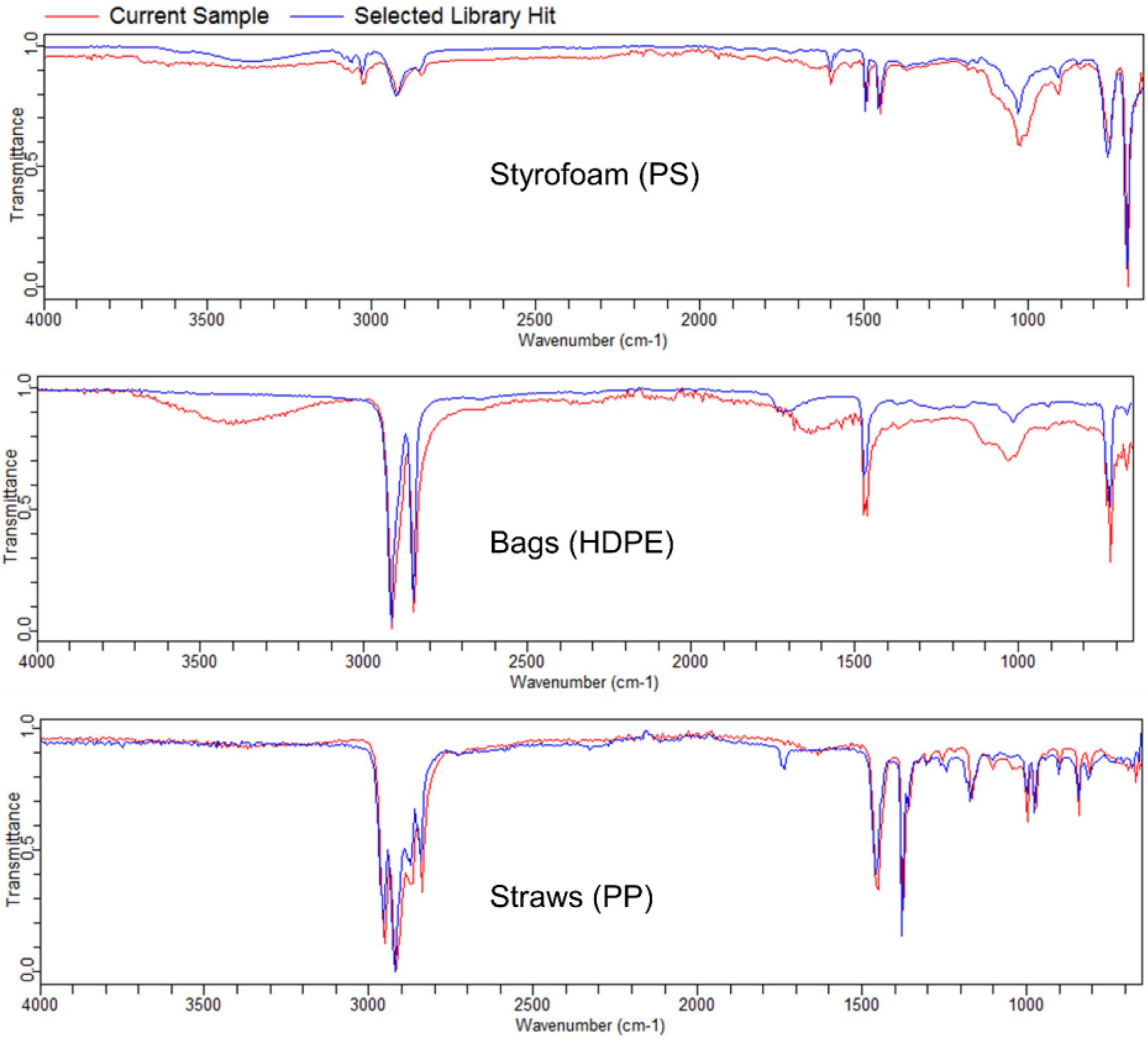


Fig. 6 FTIR of some macroplastics items found in the studied area. For typical PS resin, HDPE resin, and PP resin, styrofoam, plastic bag, and straw (Fig. 5) were examined, respectively

polymers are commonly employed in the production of daily items. PS, in particular, accounts for a significant portion of plastic waste since it is thermoplastic, hard, light, and insulating. PS was widely used in packaging, building materials, and maritime time but had limited recyclability. Rivers, rains, water treatment facilities, structural damage, boats, or direct discharge all contribute to the presence of PS resin in the maritime environment (Kwon et al., 2017). It is readily carried away by waves and wind due to its small weight. As a result, they are readily disseminated throughout the ecosystem. During beach cleanup, PS resin proved especially difficult to remove. More significantly, it has been seen to have an impact on many sorts of marine species that float-eat on the water's surface, such as clogging the gastrointestinal tract or exposing the animal to hazardous compounds (Turner, 2020).

Microplastic characteristics

Abundance

Three MP samples were collected along the coast at each beach. The distance of two samples on the same

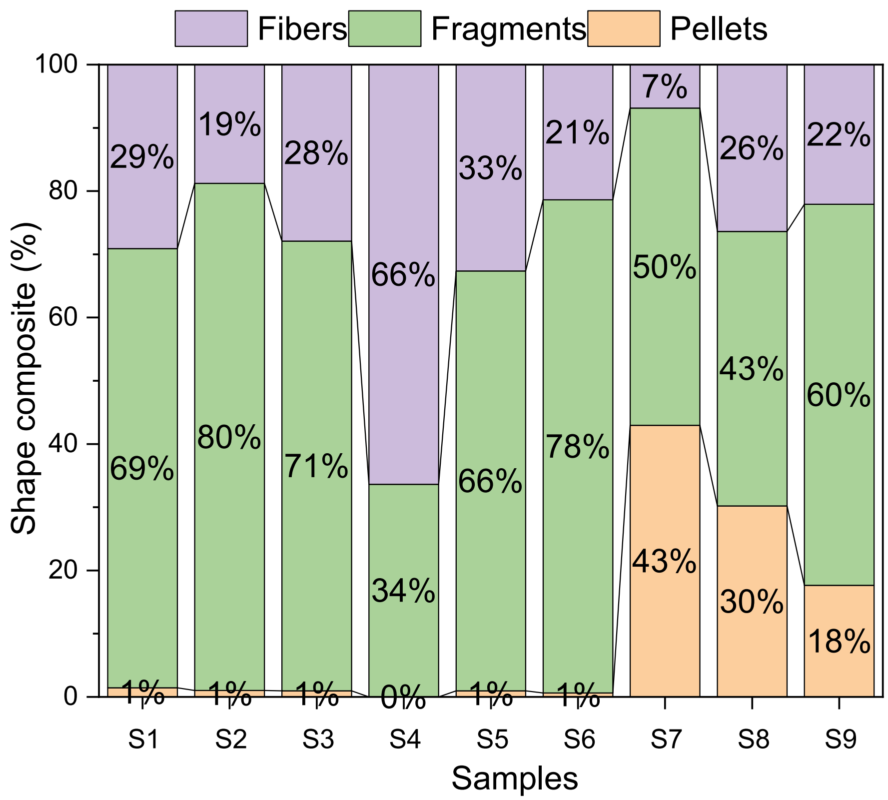


Fig. 7 MP identification in shape features

beach is 1 km apart. There are nine water samples in total, numbered S1–S9. S1, S2, and S3 were collected at Hai Tien Beach; S4, S5, and S6 were collected at Sam Son Beach; S7, S8, and S9 were collected at Hai Hoa beach. The total number of MPs collected in this research was 4897 pieces, which were dispersed

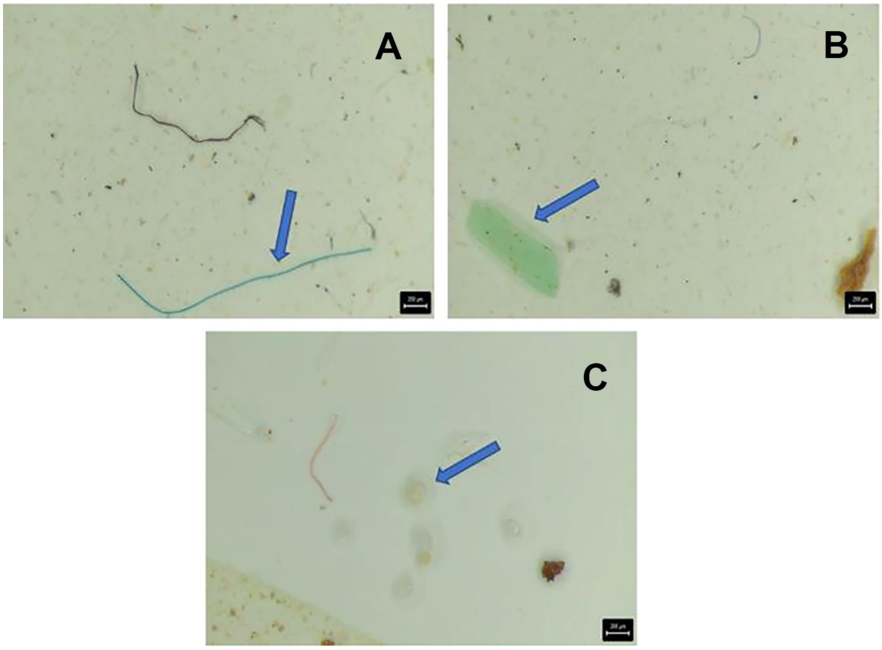


Fig. 8 Examples of different types of MPs observed using stereo microscopy. **A** Fibers, **B** fragments, and **C** pellets

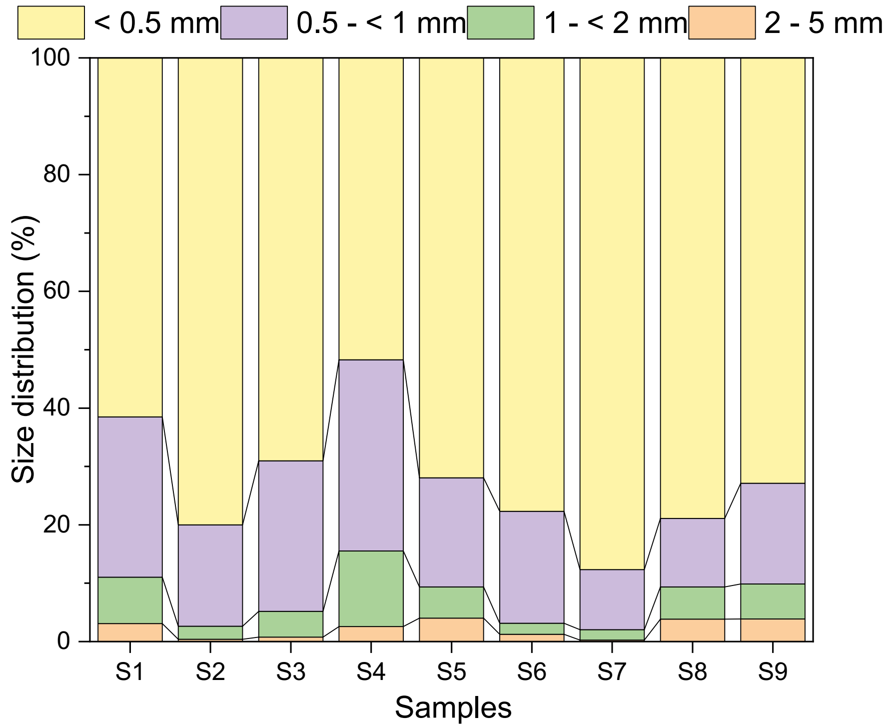


Fig. 9 MP identification in size features

throughout all sample sites from S1 to S9. Table 2 shows the abundance and number of MP collected at sample sites on the beaches of Hai Tien, Sam Son, and Hai Hoa in Thanh Hoa province.

The MP abundance in the studied area varied from 15.5 to 44.1 (items/m^3), with an average value was 30.1 (items/m^3). S2 sample on the Hai Tien beach presented the largest value (i.e., 44.1 items/m^3), whereas the minimum value was at S5 on Sam Son beach (i.e., 15.5 items/m^3). The results indicated that

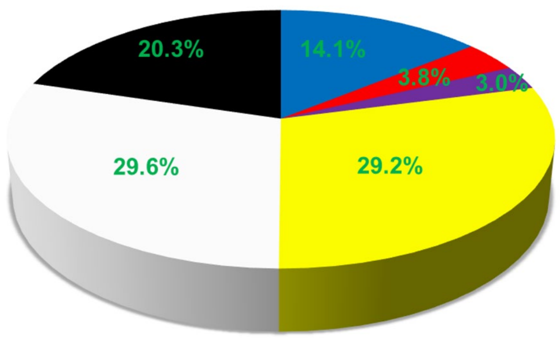


Fig. 10 The color distribution of MPs in Hai Tien, Sam Son, Hai Hoa beaches, Thanh Hoa province

despite a close distance from the Lach Hoi estuary, the MP abundance in Hai Tien and Hai Hoa beaches was higher than in Sam Son, where all wastewater from Thanh Hoa city was discharged. This result can be explained by MP properties such as small size, low density, and existence suspended in water. Besides, the abundance of MPs at a location in the aquatic environment depends on two main factors, including sources from estuaries (referred to as continental sources) such as wastewater from people living on the coast, fishing, processing, and preservation of aquatic products and exchange or dilution by cleaner water blocks on the sea (reducing MP density). Thus, for Sam Son beach, the wave dynamics are the strongest due to the lack of shielding in front of the beach. The small-grained (e.g., sediment components, MPs) are less likely to exist and are mostly swept away. In comparison, Hai Tien and Hai Hoa beaches are hidden in the bay area and Hon Me island cluster, respectively. The wave dynamics of these beaches are weak, creating conditions for the convergence of microplastics. Besides, Sam Son beach protrudes to the sea, so the water exchange with the deepwater area of the Gulf of Tonkin takes place better than the rest of the beaches, and the dilution of the content of microplastic particles occurs strong.

Currently, there is no national standard for MP monitoring worldwide. Some common sampling methods include net tow, injecting a defined volume through a filter, or injecting a defined volume through a sieve. Mesh size and sieve size were often different in published works. In this study, the data used for comparison were used with the same net-based method (i.e., net tow). Table 3 shows that the MP abundance in water at the beach of Thanh Hoa province ranges from 15.5–44.1 items/m^3, much higher than that of the Bach Dang estuary, Vietnam, and other areas such as Bohai Sea, China; Scotland; Benoa Bay, Indonesia; Qatar; and Northern Gulf, Mexico. This demonstrated the degree of MP pollution generated by wastewater from human activities such as residence, operating restaurants, hotels, aquaculture, and fishing greatly damaged the shoreline, which requires attention for mitigating strategies.

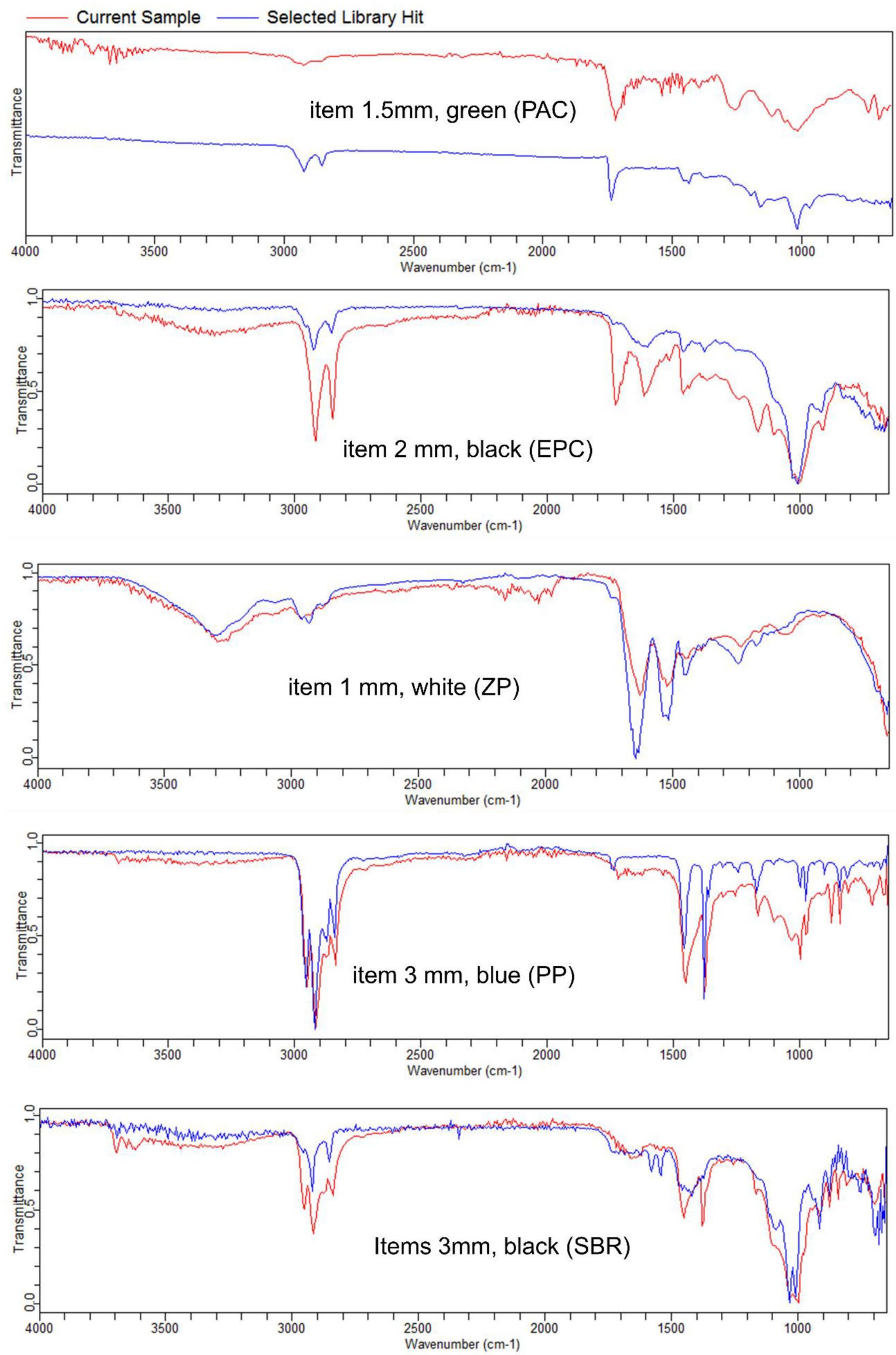
Shape features

Many studies have been published to divide MPs into many categories: pellets, fragments, fibers, films, ropes and filaments, and foam. In this study, MPs were identified with three characteristic forms: pellets, fragments, and fibers (Figs. 7, 8). The shape characteristics of the MPs in this study are shown in Fig. 7. Fragments were the predominant shape in most of the studied locations accounting for 61.4 ± 14.3%, followed by filaments attributed for 27.9 ± 14.5%, and the lowest contribution is pellets which accounted for 10.6 ± 14.3% of the total found items. MPs composed a large part of fragments because they were derived from various types of sources such as plastic bags, food packaging, fishing gear, and means of transportation (Ma et al., 2021; Sivadas et al., 2022; Zablotski & Kraak, 2019). Prolonged under the sea weather, mechanical processes, and possibly waste incineration also increase plastic fragments. Fibrous MPs account for the second major after fragments because this type is mainly derived from fibers in the washing process of textiles (De Falco et al., 2019). It is also the most commonly ingested microplastic by marine organisms, posing a significant threat to marine life in the area (Rebelein et al., 2021).

S7, S8, and S9 belonging to Hai Hoa beach contained a large number of pellets MPs (i.e., 30.3 ± 10.3% of total MPs) larger than the other two areas (i.e., Hai Tien and Sam Son beaches). This difference can be explained for two reasons. Firstly, it was reported that MPs in the shape of pellets are present in many cleaning products, such as facial cleansers, shampoo, detergent, and skincare products (Fendall & Sewell, 2009). Secondly, it is related to the administration of household wastewater treatment systems. A poor wastewater treatment system will increase the number of microplastics in water (Franco et al., 2021; Wu et al., 2022). The actual survey (also included in this study) showed that, in Hai Tien and Sam Son beaches, domestic wastewater from households, hotels, and restaurants on the coast is collected into the sewer system for centralized treatment, while in Hai Hoa, these wastes are discharged directly to the beach. This is the reason why MPs present in Hai Hoa beach water are significantly higher than in Sam Son and Hai Tien.

Size features

Size features of MPs are shown in Fig. 9. Among collected samples at three beaches (i.e., Hai Tien, Sam Son, and Hai Hoa), MPs with small sizes in the range of 100–500 µm were the main proportion, accounting for 70.2 ± 7.6% of total particles; followed by MPs with sizes in the range of 500–1000 µm, accounting for 23.5 ± 4.4% of total items. The MPs with sizes ranging from 1000 to 2000 µm (or 4.9 ± 2.3% of total items). The size range of 2000–5000 µm is attributed to the smallest part (i.e., 1.4 ± 1.2% of the total number of items). With the predominant small-sized microplastic composition, the result implied that the microplastics originated mainly from domestic wastewater sources, including wastewater from clothes washing machines, wastewater from cleaning activities (additives of detergents, cosmetics, toothpaste), and activities of transportation (microplastics are formed by worn tires) (Yukioka et al., 2020).


Current Sample
Selected Library Hit
item 1.5mm, green (PAC)
item 2 mm, black (EPC)
item 1 mm, white (ZP)
item 3 mm, blue (PP)
Items 3mm, black (SBR)
Transmittance
Wavenumber (cm-1)
4000
3500
3000
2500
2000
1500
1000
0.0
0.5
1.0

◂**Fig. 11** FTIR of MP items found in surface water. Besides, the polymer type that is similar to macroplastics, there are some other types such as polyethylene-acrylate (PAK), styrene/butadiene rubber gasket (SBR), ethylene/propylene copolymer (EPC), and zein purified (ZP)

Table 2 Current status of MPs in surface water in Thanh Hoa province

Sample name	Beach	Number of MPs (items)	Abundance (items/m^3)
S1	Hai Tien	969	26.2
S2		495	44.1
S3		523	38.9
S4	Sam Son	348	18.7
S5		524	15.5
S6		318	24.5
S7	Hai Hoa	787	41.6
S8		417	33.8
S9		516	30.1
Average abundance			**30.1**

Color features

MP colors were identified with seven colors, including blue, red, purple, yellow, white, and black. The result is presented in Fig. 10 and Table 4. A total of 4897 MPs items in water at three beaches (i.e., Hai Tien, Sam Son, and Hai Hoa) was found, in which white pieces were 1451 items, accounting for 29.6%; yellow pieces were 1431 items, accounting for 29.2%; black pieces were 992 items, accounting for 20.3%; blue pieces were 691 items, accounting for 14.1%; red pieces were 186 items, accounting for 3.8%; and purple pieces were 146 items, accounting for 3% (Fig. 7). Thus, the color of microplastics was ranked in order from highest to lowest as follows: white > yellow > black > blue > red > purple. Yellow, white, and black were the colors that account for a large percentage of microplastics in the study area. These are also commonly used colors in products that are likely to emit microplastics into the marine environment, such as synthetic fiber clothing, additives in shampoo, toothpaste, facial cleansers, cosmetics, and dust caused by worn tires during operation. Some items have been identified polymer type through FTIR method combined with spectrum library. The result is shown in Fig. 11. In addition to the polymers recognized in macroplastics analysis (i.e., PS, HDPE, PP), many other forms of plastics have been discovered. Data demonstrates that, in addition to being derived from the degradation of macroplastics, MPs may also be derived from automobile tire wear, the air, and skincare products (Fendall & Sewell, 2009; Han et al., 2020; Nachite et al., 2019; Uheida et al., 2021; Wang et al., 2021; Yukioka et al., 2020).

Table 3 Comparison with some previous studies

Location	Sampling method	Abundance (items/m^3)	Reference
Bohai Sea, China	Net tow, mesh size: 330 µm	0.49	(Zhang et al., 2020)
Scotland	Net tow, mesh size: 330 µm	0.627	(Russell & Webster, 2021)
Benoa Bay, Indonesia	Net tow, mesh size: 330 µm	0.7	(Suteja et al., 2021)
Quatar	Net tow, mesh size: 120 µm	0.71	(Castillo et al., 2016)
Bach Dang estuary, Vietnam	Net tow, mesh size: 80 µm	0.97–3.42	(Duong et al., 2020)
Colombia Caribbean and Pacific	Net tow, mesh size: 500 µm	0.01–8.96	(Garcés-Ordóñez et al., 2021)
Northern Gulf, Mexico	Net tow, mesh size: 335 µm	5.0–18.4	(Di Mauro et al., 2017)
Nakdong River mouth, Korea	Net tow, mesh size: 330 µm	0.62–57	(Kang et al., 2015a, b)
North Sea, Germany	Net tow, mesh size: 100 µm	0.1–245.4	(Lorenz et al., 2019)
Black Sea	Net tow, mesh size: 200 µm	1200	(Aytan et al., 2016)
Urban Crater Lake in Erzurum, Turkey	Net tow, mesh size: 300 µm	0.04–0.13	(Ivar Do Sul et al., 2014)
Thanh Hoa, Vietnam	Net tow, mesh size: 80 µm	15.5–44.1	This study

Table 4 The color composition of MPs in the marine environment of Hai Tien, Hai Hoa, and Sam Son

Sample name	Beach	Color composition (%)					
		Blue	Red	Purple	Yellow	White	Black
S1	Hai Tien	11.0	1.5	1.9	50.5	20.7	14.3
S2		12.3	14.5	1.6	37.6	9.9	24.0
S3		19.9	0.4	1.1	33.5	23.3	21.8
S4	Sam Son	12.1	7.8	13.8	20.7	18.1	27.6
S5		19.8	2.5	4.4	15.8	36.6	20.8
S6		13.5	3.1	2.2	32.7	35.2	13.2
S7	Hai Hoa	7.9	1.5	1.0	13.9	56.2	19.6
S8		15.6	3.1	3.4	34.1	21.8	22.1
S9		20.0	4.3	2.7	13.8	34.7	24.6
Average		14.1	3.8	3.0	29.2	29.6	20.3

Conclusions

The results showed that macroplastics (especially polystyrene) make up the main component, a persistent waste with low recyclability. MPs were present in the marine water at all sampling points of three beaches (i.e., Hai Tien, Sam Son, Hai Hoa) in Thanh Hoa province. The abundance of MPs was relatively high compared to published works in Vietnam as well as worldwide, which poses a severe threat to marine life in the aquatic environment. The abundance of MPs at beaches depends mainly on factors such as the source of discharge and topographical and hydrological factors of the beach area. The characteristics such as the shape, size, and color of microplastics show that the origin of MPs comes from wastes in the continent released by rivers through estuaries. Besides, other anthropogenic activities are also the main sources, such as domestic wastewater of people living on the coast, fishing, aquaculture, and seafood processing activities. In conclusion, this study provides comprehensive information and data as a reference for establishing long-term control and monitoring measures for MPs in this area.

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Author contribution Dao Dinh Cham: conceptualization, methodology, project administration. Duong Thi Lim: formal analysis, validation, supervision. Nguyen Thi Huong Thuy: investigation, resources. Nguyen Thi Hue: data curation, resources. Nguyen Thi Lan Huong: funding acquisition, writing original draft. Nguyen Thi Huong Thuy: data curation, resources. Dang Tran Quan: data collection, analysis. Dao Ngoc Nhiem: investigation, resources, visualization. Pham Ngoc Chuc: data collection, analysis. Nguyen Thi Ha Chi: data curation, resources. Duong Cong Dien: data collection, methodology, software. Bui Thi Thu: data collection, analysis. Nguyen Quang Bac: visualization, writing – review and editing.

Data availability The data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Conflict of interest The authors declare no competing interests.

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