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Occurrence and distribution of microplastics in surface sediments from the Gulf of Thailand

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ABSTRACT

This study investigated the distribution and characteristics of microplastics in surface sediments of the Gulf of Thailand (GoT), and discussed the correlation between sediment grain size and microplastic content. The results indicate the abundance of microplastics is 150.4 ± 86.2 pieces/kg dry weight, representing a medium microplastic pollution level compared to other sea areas. Small microplastics (0.5–1 mm) take up > 70% of total microplastic numbers. Fibrous microplastics are the dominant component of microplastics. According to micro-Fourier transform infrared spectroscopy, rayon (37%) and polyester (PES: 16%) are the most typical polymer types found in sediments. The results imply that secondary microplastics are the dominant pollutant, while fibrous microplastics are mainly from municipal sewage discharge. We also find that inconspicuous correlation between grain size and microplastics, which is caused by the multi-sources and different flow field. This study deepens our understanding of the environmental risks posed by microplastics to marine ecosystems in the GoT.

1. Introduction

With the mass manufacturing of plastics in the 1950s, synthetic polymers were increasingly displayed in public spaces (Thompson et al., 2004). Plastics brought us widespread convenience, but also serious unforeseen environmental issues (Schymanski et al., 2017; Bergmann et al., 2017). Mismanaged plastic debris became an emerging pollutant which impacted aquatic ecosystems beginning in the early 1970s (Thompson et al., 2004). Nowadays, no place can be free of plastic pollution: nor the deep ocean, and nor the polar regions (Jambeck et al., 2015; Van Cauwenberghe et al., 2013). Bulk plastic litters are gradually broken into smaller pieces under the combined actions of physical abrasion and UV radiation. The National Oceanic and Atmospheric Administration (NOAA) now defines the term "microplastics" as tiny ubiquitous plastic particles < 5 mm in diameter. Microplastics can be categorized as being of primary or secondary origin (GESAMP2015). Many aquatic species in the oceans mistake the tiny colorful balls of microplastic for food, ending up with them in their digestive systems (Tanaka and Takada, 2016; Barnes et al., 2009; Bhattacharya et al., 2010; Watts et al., 2014). However, that is not the final stage of biological uptake, as they accumulate ultimately in the human body (Schwabl, 2019). As a consequence, microplastic pollution of the ocean environment is capturing scientists' attention (Browne et al., 2011; Woodall et al., 2014). The general public are mainly aware of the plastic litter floating on the surface of the seas and oceans, whereas several studies conclude that plastic debris in marine sediments are at high abundance levels as well (Cózar et al., 2014; Browne et al., 2010; Peeken et al., 2018). Some special marine areas, such as

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off-shore wind farms, have an extremely high microplastic abundance, as much as two orders of magnitude higher than that in the adjacent sea areas (Wang et al., 2018; Zhu et al., 2018). Although microplastics appear to keep afloat, microbes and organics are tend to accumulate on them, which increase the density of microplastics (Michels et al., 2018, Thompson et al., 2004, Van Cauwenberghe et al., 2013). Some researches show that microplastics in the ocean will be deposited on the ocean floor in the end (Thompson et al., 2004, Andrady, 2017). Therefore, researches on microplastics in sediment record are important.

Bay areas occupy a highly special position in social economic development, not only for their high population densities, but also the highly efficient industrial structures. Due to increased human activities, bay areas are suffering terrible pollution currently, such as air pollution (Jantunen, 1998), heavy metal pollution (Zhuang and Gao, 2014; Qiao et al., 2015), and pollution from persistent organic pollutants (Noreña-Barroso et al., 2004; Hu et al., 2017). Because of their unique geographical position under the joint influence of human activities and land-sea interactions, bay areas are the ideal regions for microplastics research. Scientists are zealous about researching on microplastic pollution levels in bay areas, as the levels have steadily increased in recent decades, especially in the Tokyo Bay (Tanaka and Takada, 2016; Matsuguma et al., 2017), San Francisco Bay (Sutton et al., 2016), and Gulf of Mexico (Phillips and Bonner, 2015; Wessel et al., 2016).

The Gulf of Thailand (GoT), a semi-enclosed epicontinental sea surrounded by the Indo-China Peninsula and Malay Peninsula, has attracted a lot of attention recently as the GoT ecosystem is particularly vulnerable to human activities (Srisuksawad et al., 1997), and increased anthropogenic activity in the area has resulted in severe environmental pollution (Hu et al., 2017; Wattayakorn et al., 1998; Qiao et al., 2015). However, the potential threats posed by microplastics in the GoT are still limited. Only one research about microplastics in sediment core was published (Matsuguma et al., 2017). Matsuguma et al. (2017) found a marked decline in abundance of microplastics from surface to the deep. However, their samples only located in the Upper GoT, which do not cover the whole GoT. Therefore, this study collected more sediment samples to examine the distribution and characteristics of microplastics and determine the contamination level and potential sources of polymer synthesis pollutants in the GoT.

2. Materials and methods

2.1. Study area and sample collection

The GoT located in the southwest South China Sea, is a semi-enclosed marine embayment, which is surrounded by Malaysia, Thailand, Vietnam, and Cambodia (Fig. 1). The GoT consists of two parts, the upper Gulf, which is the northernmost part, and the lower Gulf. The water depth of the GoT is relatively shallow, with a mean depth of approximately 45 m and most of the water depth is lower than 80 m. Seasonal variation of current in the GoT is also an important characteristic (Fig. 1). In winter, a clockwise gyre develops in the lower gulf; however, the upper GoT generates a counterclockwise gyre. In summer, a number of eddies and stronger currents contribute to more complex flows. Large clockwise gyre in the lower gulf is also common (Buranapratheprat and Bunpapong, 1998).

In this study, eighteen surface sediment samples were collected on a regional scale during cruises from 2010 to 2011 by China – Thailand joint cruises (Fig. 1). The samples were collected using a stainless steel box sampler. All sediment samples (0–5 cm) were wrapped in pre-combusted aluminum foil and stored at −4 °C until analysis in the lab.

2.2. Microplastic isolation

All the samples were freeze-dried for 48 h and weighed. The method to extract microplastics was modified from Thompson et al. (2004) and Nuelle et al. (2014). The pilot experiment showed that the method we selected had a high extraction rate. NaCl is cheap and environmental friendly as well. Firstly, 40 g sediments were transformed into a 500 mL clean glass beaker (washed with deionized water and dried at 60 °C). The experiment set two parallel samples. A solution of 30% H_2O_2 was used to remove the organic matter. Then we introduced 400 mL of saturated NaCl solution (1.2 g/cm^3) into each beaker and stirred for 1 min. After 4 h, the supernatant was filtered through a gridded mixed cellulose ester filter paper (20 μm pore diameter, 50 mm, Shanghai Xinya Corporation, China) with a vacuum pump. When the samples are still standing, the glass beakers are covered by aluminum foil. The procedure of adding saturated NaCl solution and filtering was repeated three times. In this study, two blank samples were used saturated NaCl solution for pre-extraction to estimate the background contamination. To avoid contamination in the experiment, all the laboratory technicians wear cotton coats.

2.3. Polymer identification

After drying naturally, the plastic-like items were counted using a stereomicroscope (Leica Microsystems, Wetzlar, Germany) providing up to 80-fold magnification. The optical images of particles were taken by a digital camera that was connected to the microscope. To identify the microplastics, representative plastic-like particles (27% of plastic-like particles in the sediments were selected) were analyzed using a micro-Fourier transform infrared spectroscope, μ-FT-IR Nicolet 10 (Thermo Scientific, Waltham, MA, USA), following the method described by Yang et al. (2015). The polymer types of microplastics were identified by comparing all the spectra against a database (HR Spectra IRDemo, Hummel Polymer and Additives, Polymer Laminate Films, Cross-sections Wizard and Aldrich Vapor Phase Sample Library) using the OMNIC software.

3. Results and discussion

3.1. Abundance level of microplastics in the GoT

All the sampling sites located in the GoT are suffered plastic pollution, as microplastics are found in each sample (Fig. 2). The abundance of microplastics ranged from 25.0 pieces/kg to 362.5 pieces/kg, and the average concentration was 150.4 ± 86.2 pieces/kg. The concentration in our study was slightly lower than Matsuguma et al. (2017). Cause the cores locations in Matsuguma et al. (2017) were gathered in the upper GoT, which near the estuary. As in other areas, fibers were the most dominant component of polymer particles (Browne et al., 2011; Zhu et al., 2018; Wang et al., 2018), which were up to 87.9% of the total. The concentration of granules was 7.9% of the whole sample. Both the densities of fragments and films were lower than 1%; the films were rarely detected in all kinds of morphologies.

All collected samples in this study contain microplastics, which means that the sediments in GoT are contaminated with plastics. Meanwhile, microplastic abundance at site T14 is 17-fold higher than that at site T4, indicating that microplastic abundance in the GoT sediments is heterogeneous. Microplastic abundance is relatively high in the areas receiving river material at the top of the upper GoT. It is speculated that runoff brings a large amount of sediment which carries plentiful plastics and may also be related to aquaculture activities (Pauly and Chuenpagdee, 2003; Liebmann et al., 2018). The site with the highest content (T14) of microplastics is located at the bottom of the upper GoT, and the abundance of microplastics at the adjacent sites is relatively high as well. As the sea area broadens and weakens hydrodynamic force, a large amount of microplastics deposited there. This may also be related to the circulation of two opposite currents passing through this area (Buranapratheprat and Bunpapong, 1998).

The abundance of microplastics in the surface sediments of the GoT is about half that of the Mediterranean Sea (Alomar et al., 2016; Abidli

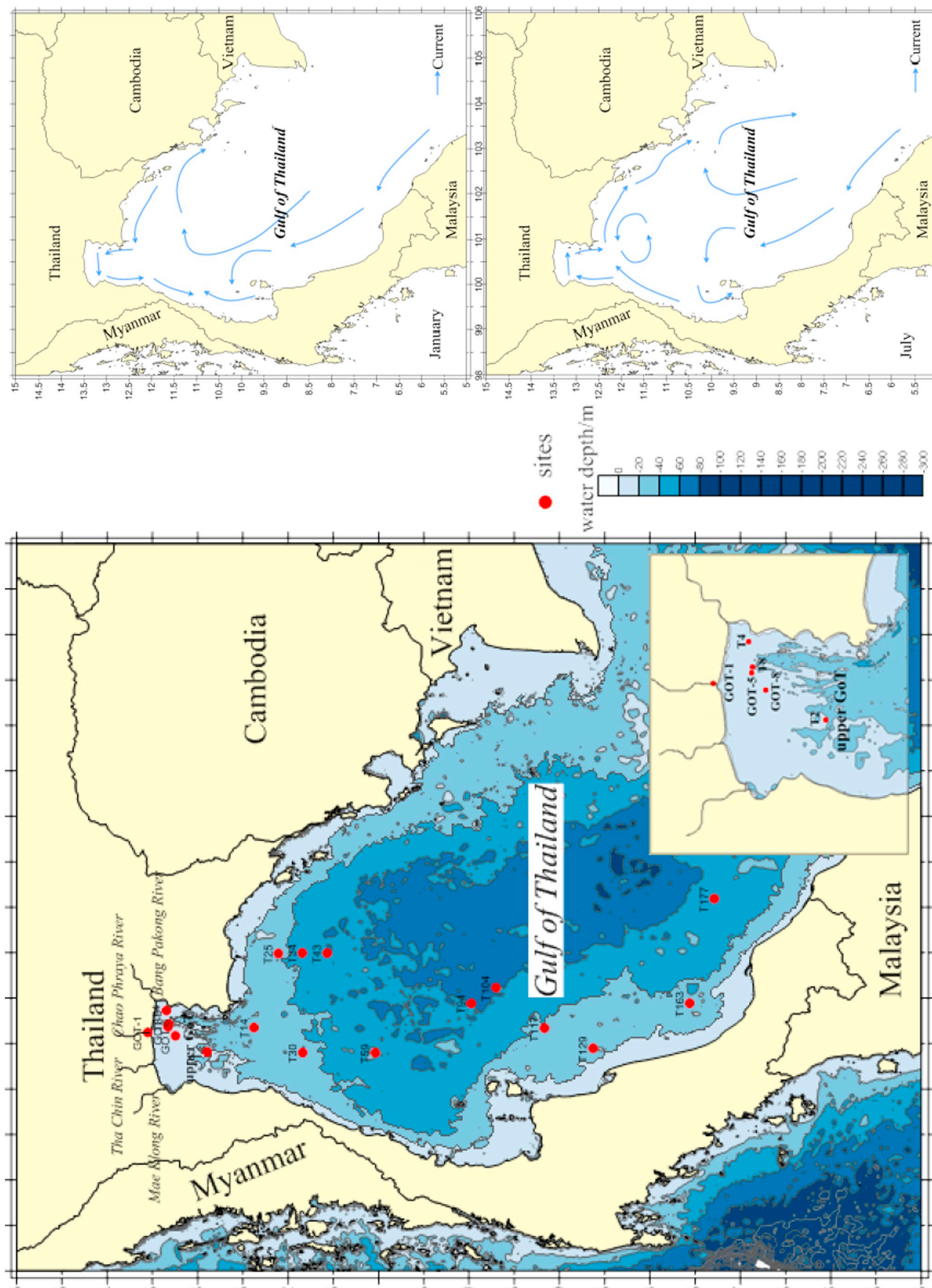

Fig. 1. Location of the Gulf of Thailand and mean circulation in winter and summer. Modified from Buranapratheprat and Bunpapong, (1998).

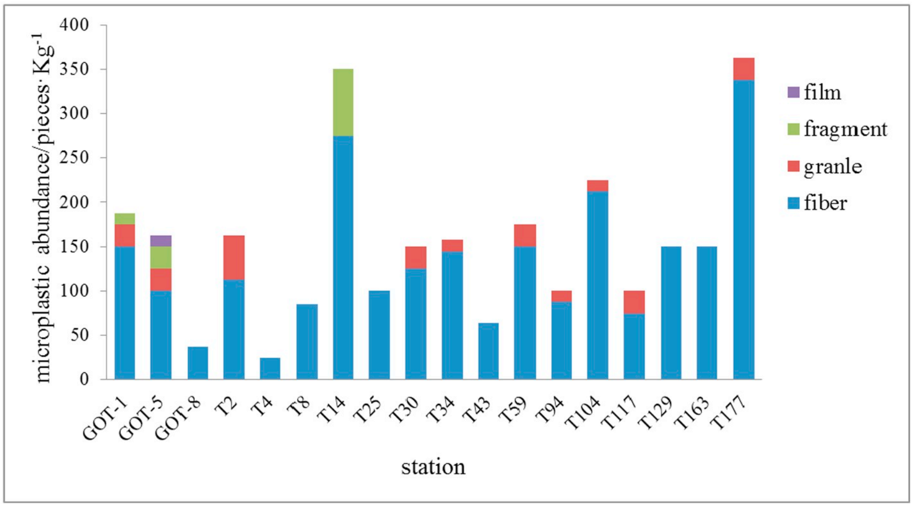

Fig. 2. Composition of microplastics based on shape in surface sediment of the Gulf of Thailand.

Table 1
Comparison of microplastic abundance in different countries or regions.

Location	Country	Abundance	Type	Reference
Estuarine	UK	35 pieces/kg	Sediment	Thompson et al., 2004
Subtidal	UK	86 pieces/kg	Sediment	Thompson et al., 2004
Continental shelf	Belgium	116 pieces/kg	Sediment	Claessens et al., 2011
Beach	Belgium	156 pieces/kg	Sediment	Claessens et al., 2011
Bohai Sea	China	127.9 pieces/kg	Sediment	Yu et al., 2016
Lagoon	Italy	1445.2 pieces/kg	Sediment	Vianello et al., 2013
Gulf of Mexico	/	23.3 pieces/m^2	Sediment	Wessel et al., 2016
Persian Gulf	/	61 pieces/kg	Sediment	Naji et al., 2017
Tunisia coastal zone (Mediterranean)	Tunisia	316 pieces/kg	Sediment	Abidli et al., 2018
Mediterranean	/	270 pieces/kg	Sediment	Alomar et al., 2016
Gulf of Thailand	/	150 pieces/kg	Sediment	This study
South China Sea	China	6870 pieces/kg	Sediment	Qiu et al., 2015
Yangtze River estuary	China	121 pieces/kg	Sediment	Peng et al., 2017
Guanabara Bay	Brazil	12–1300 pieces/m^2	Sediment	Carvalho and Neto, 2016
Bohai Bay	China	164.5 piece/kg	Sediment	Dai et al., 2018
Tokyo Bay	Japan	1845 piece/kg	Sediment	Matsuguma et al., 2017
Southeastern United States	US	43–443 piece/kg	Sediment	Yu et al., 2018

et al., 2018), but still comparable to the Bohai Sea (Yu et al., 2016) and the Gulf of Mexico (Wessel et al., 2016). The content of microplastics in lakes and lagoons (Vianello et al., 2013) is significantly higher than that in the oceans; therefore, it can be concluded that sediments in enclosed waters capture microplastics and deposit them more easily. This can also explain the reason that microplastics in the sediments of the Mediterranean are higher than those in the GoT and Bohai Sea (Table 1). The plastic content in the beach is much higher than that in the offshore sediments, which might be related to tourism activities on the beach (Zhou et al., 2018). The more developed the bathing beach, the more likely it is to be exposed to plastic waste. Therefore, the abundance of microplastics in the Tokyo Bay is far higher than other bay areas.

As the extraction methods of microplastics do not have established corresponding standards, the methods used in each laboratory vary significantly, and the flotation liquids used are also diverse (Chae et al., 2015). Therefore, the comparison between different studies is problematic. Nevertheless, the results obtained by different laboratories differ by 2–3 orders of magnitude, even with sediment samples that are from the same sea area (Wang et al., 2018; Zhu et al., 2018). Sampling methods can also have a great impact on the experimental results (Chae et al., 2015).

3.2. Characteristics of microplastics in the GoT

A total of 133 selected particles were analyzed with micro-Fourier transform infrared spectroscope. From them, 48% were identified as common polymer materials. Eleven types of common polymer materials (Fig. 3a): polyethylene (PE), polypropylene (PP), polyester (PES), polyamide (PA), rayon, epoxy resin, nylon, polyvinyl alcohol (PVA), polyvinylchloride (PVC), acrylic, and styrenic block copolymers (SBS), were detected in samples. Some particles were divided into polymers but always appeared singly; we identify those polymers as "other synthetic." The results indicated that rayon was the most prevalent component (Fig. 3b), with PES next, and the number of PES, acrylic, and epoxy resin particles decreased in sequence. The size of all the particles was smaller than 5 mm and was identified as microplastic (Thompson et al., 2004). The particle size range was from 0.1to 0.5 mm which dominated, and 0.5 to 1 mm was the second largest group. The groups mentioned before (size range from 0.1 to 1 mm) accounted for 71%. The remaining contents (size smaller than 0.1 mm and larger than 1 mm) were 29%.

Unlike microplastics found in water in the form of fragments and films, fibrous microplastics accounted for the largest proportion of sediment samples in this study. This result is similar to other studies relating to sediment in the literature (Zhao et al., 2014; Wang et al., 2018; Zhu et al., 2018). The fact that fibers have a relatively large specific

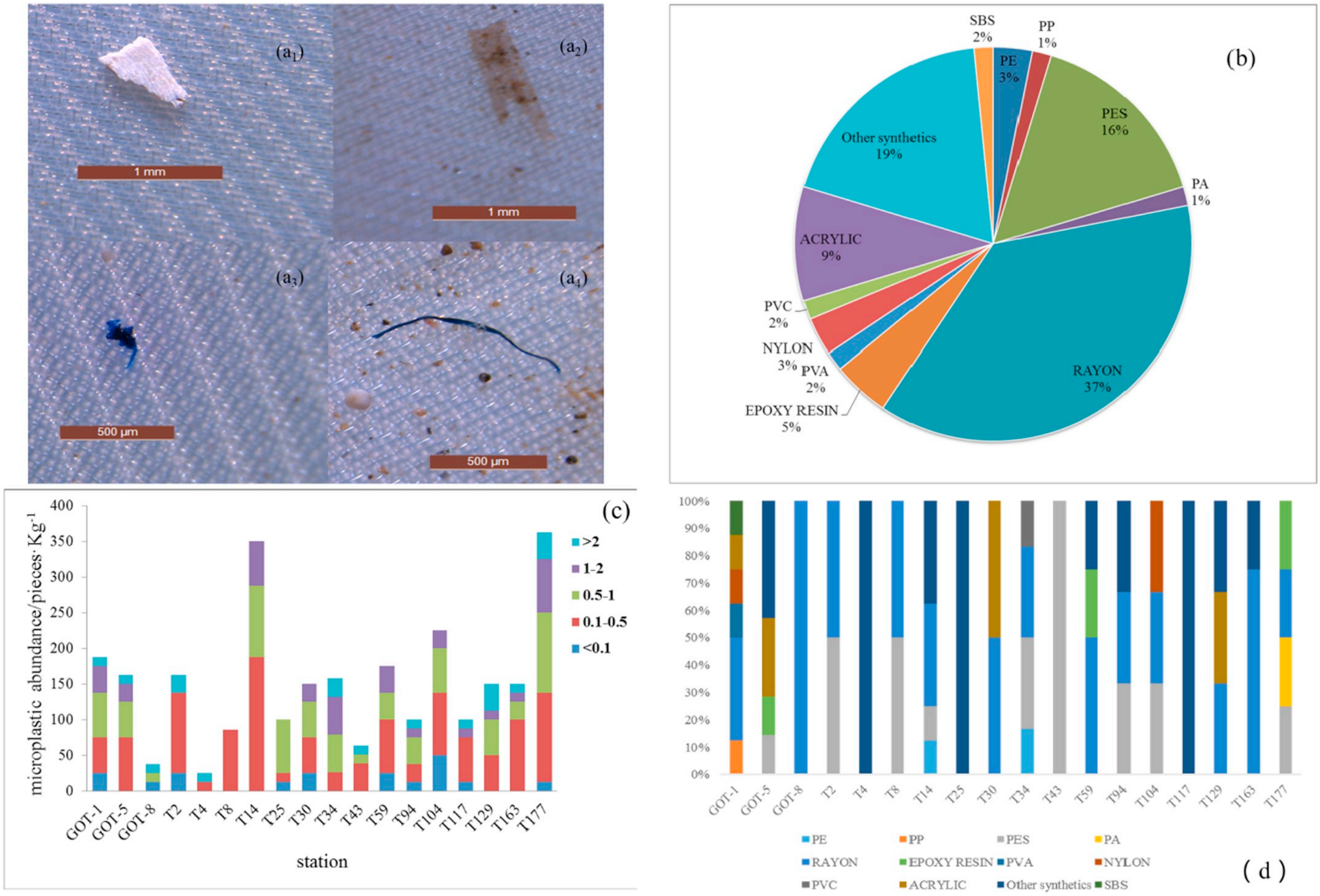

Fig. 3. Photographs of plastic items in the surface sediments (a_1–a_4); composition of microplastics based on types (b); size (mm) (c) in the Gulf of Thailand and composition of microplastics in each sites.

surface area contributes to such a result (Chubarenko et al., 2016). It has been demonstrated that fibers were the most dominant type found (88%) in the Persian Gulf (Naji et al., 2017). In the Telascica Bay (Eastern Adriatic), filaments account for 90% of all seafloor plastics (Blašković et al., 2017). Yu et al. (2018) showed that approximately half of the particles were thread-like and fibrous materials in the southern United States coast. However, in other bay areas, such as the Tokyo Bay, Guanabara Bay, and the Gulf of Mexico, fragments contributed to the dominant component (Matsuguma et al., 2017; Sutton et al., 2016; Phillips and Bonner, 2015; Wessel et al., 2016).

PES and rayon are the dominant components in this study; however, this finding is different from the results of Duis and Coors (2016) and Frère et al. (2018) which revealed that PE, PP and PS are the most frequently found polymers. These authors showed a higher abundance of PE and PP in sediments, which represented approximately 63–89% of all microplastics. A research indicated that PE and PP are the most common types of plastic debris collected from the North Atlantic subtropical gyre (ter Halle et al., 2017). For other bay areas (the Tokyo Bay, Guanabara Bay, and the Gulf of Mexico), PP and PE are also dominant components (Matsuguma et al., 2017; Sutton et al., 2016; Phillips and Bonner, 2015; Wessel et al., 2016). However, PET contributes to the master place in the southeastern United States, which is the only bay area that has microplastics in the form of fibers (Yu et al., 2018).

The grain size of sediment in the study area was relatively coarse and consisted of fine sand and coarse silt. Most of the sites were characterized by a very high percentage (higher than 90%) of sand and silt; while the site GOT-1 was an exception (the content of clay over 13%).The mean size was 3.7φ, while grain size ranged from 2.3 φ to 6.5 φ. Meanwhile, the grain sizes of sites from the upper GoT were both the finest and the coarsest. The sediment collected from top of the upper GoT had finer grain sizes, whereas grain size of sediment in the bottom of the upper GoT was coarser, and sites located in that area contained plenty of shell debris. One of the sites (T14) with the highest content of microplastics is located at the bottom of the upper GoT, and the abundance of microplastics at the adjacent sites is relatively high as well. As the sea area broadens and weakens the hydrodynamic force, this results in a large amount of deposition of microplastics. It may also be related to the circulation of two opposite currents passing through this area (Buranapratheprat and Bunpapong, 1998). Another site that is close to the port has the highest abundance either (Hu et al., 2017).

Spatial interpolation of sediment grain size and microplastic content shows that there is a clear correlation between them (Fig. 4). Fig. 4 shows that the high microplastic content exists in stations with coarse grain size, while the study of Wang et al. (2018) in the Yellow Sea also denotes a negative correlation between grain size and microplastics abundance. However, the phenomenon shows in Fig. 4 is inveracious, the results of this study indicate that the correlation between microplastics content and median particle size is very low, the same as the sorting (Fig. 5). It shows that the correlation between the grain size of sediment and the content of microplastics is not clear, which indicates that the distribution of microplastics in the GoT is also affected by other factors (Cole et al., 2011; Mathalon and Hill, 2014). The abundance of microplastics in sediments is a coupling of multi-factors, including sources, hydrodynamic characteristics and sediment properties. The sample sites scattered in the GoT (a large area) may have different

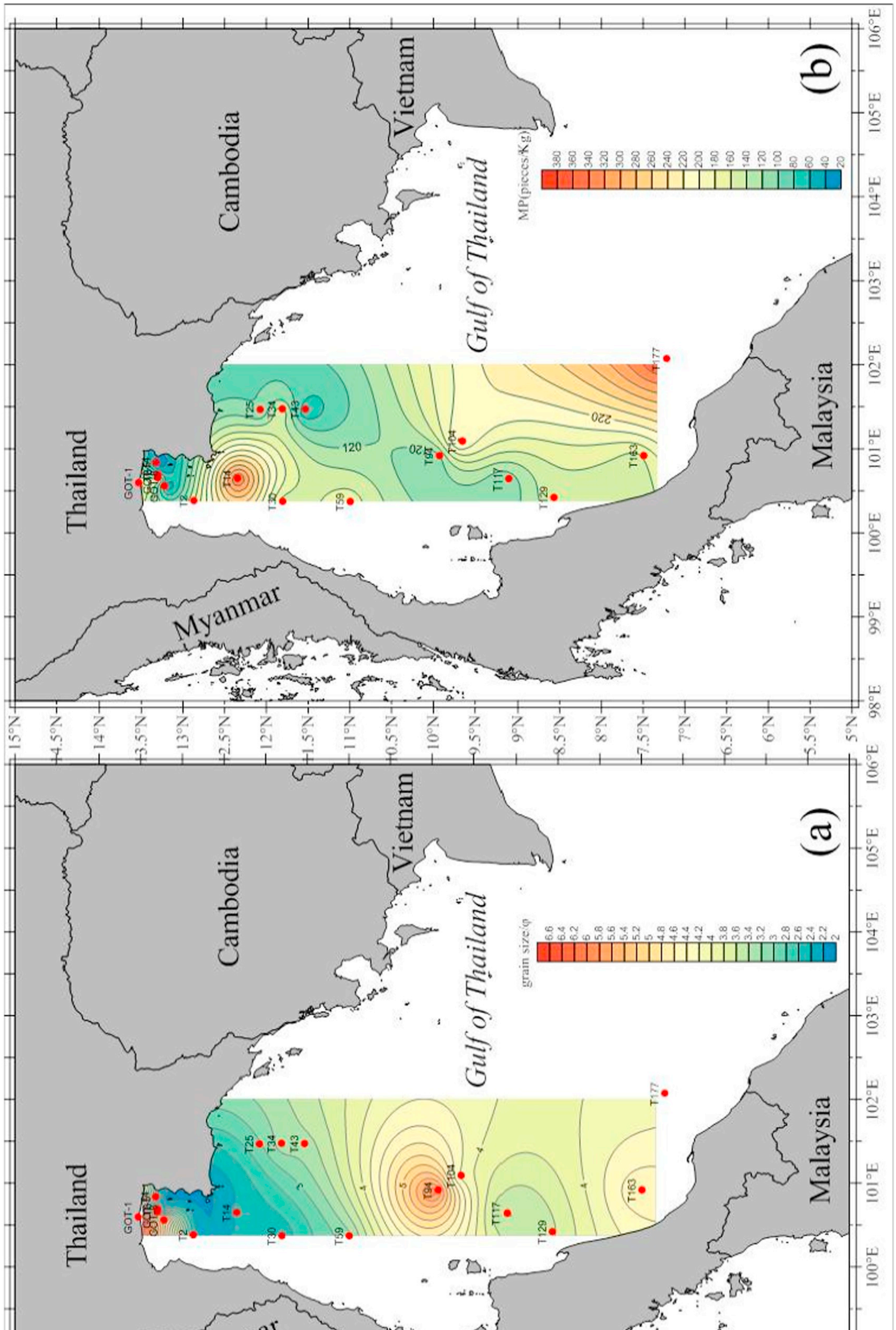

Fig. 4. Spatial distribution of the sediment grain size (a) and microplastic abundance (b) in the Gulf of Thailand.

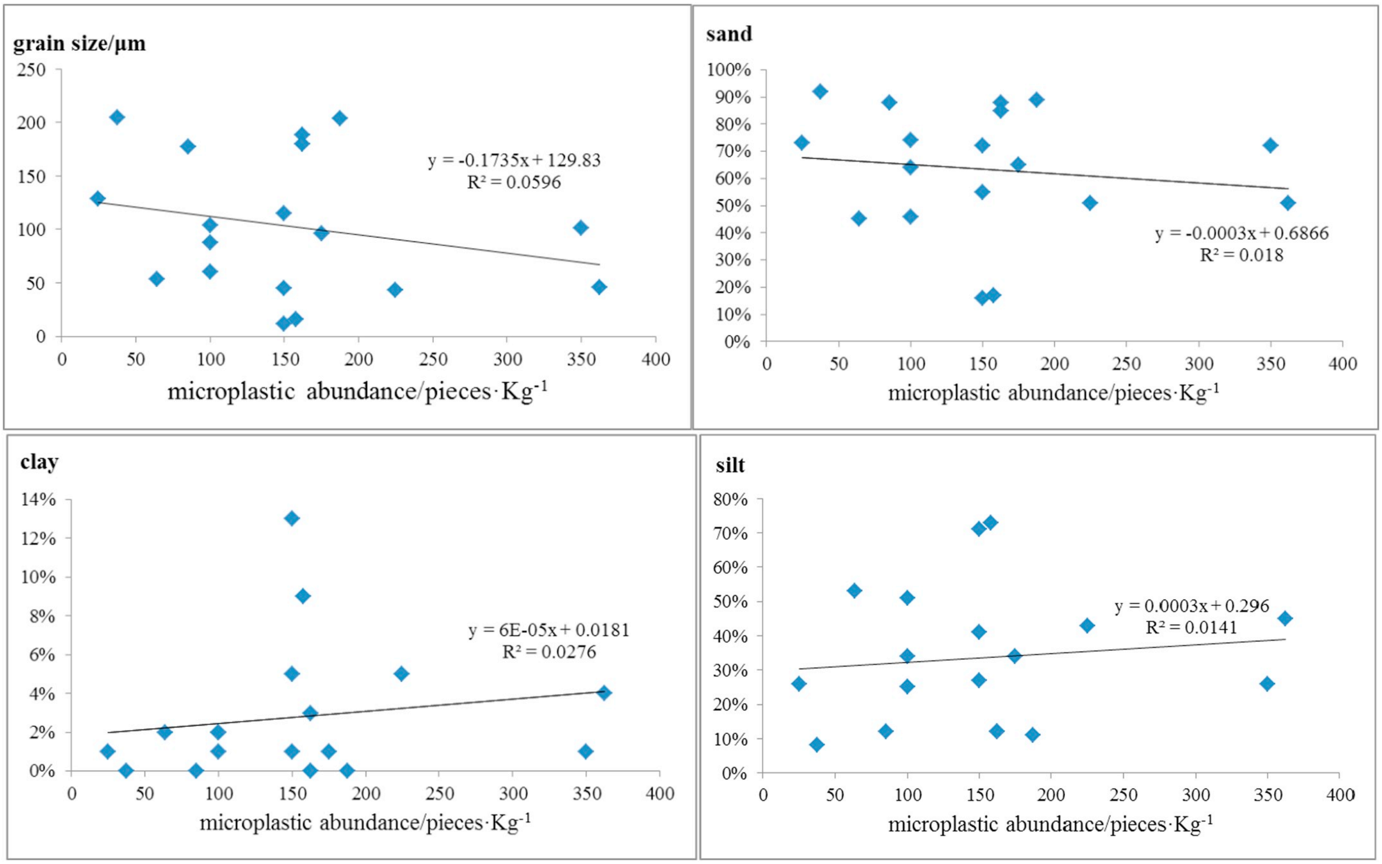

Fig. 5. Correlations between the microplastic content and sediment composition in the Gulf of Thailand.

material sources, and the different flow field between regions may also be the reason for the inconspicuous correlation between the particle size and microplastics (Qiao et al., 2015; Hu et al., 2017; Anukul and Mahunnop, 1998). It may also be that some components in sediments control the distribution of microplastics, or that sediment of a specific grain size is related to the distribution of microplastics, which needs further experimental proof.

3.3. Potential sources and risks of microplastics in the GoT

The high number of fragments and fibers indicates that the breakdown of large plastic items into secondary microplastics occur through some mechanical forces, either by photolysis, thermo-oxidation, thermo-degradation and possibly via biodegradation processes (Laglbauer et al., 2014; Zhao et al., 2016). PES and rayon are dominant components in this study. These two materials are mostly used as textile materials (Cequier et al., 2014; Mason et al., 2016). Therefore, it can be inferred that most of the plastics in the sediments of this sea area come from clothes and are related to municipal sewage discharge (Wang et al., 2019). Besides this, the results of μ-FT-IR indicate that there are many coating materials, and fishery activities and maritime transportation contribute to this kind of microplastic. The microplastic diversity index is 0.79, in reference to the method of Wang et al. (2019). The microplastics diversity index in the upper GoT is generally lower than that in the lower GoT, indicating that the source of microplastics in the surface sediments of the upper GoT is relatively simple. However, compared with other sea areas, the sources of microplastics in the GoT are more complex (Wang et al., 2019).

Plastic has hydrophobic characteristics, so it is inclined to adsorb persistent organic pollutants (POPs) in the environment. The adsorption of POPs by microplastics has been proven by many studies (Zhang et al., 2015; Brennecke et al., 2016). However, it remains to be seen if the concentration of POPs can be estimated simply by the content of microplastics, as well as can the contamination condition of POPs in the sea area be accurately reflected. This remains unknown, but compared to the research of Hu et al. (2017), it is found that in the sea areas with high abundance of microplastics, the concentration of PHAs is also high. This is reflected in the areas located in the top of the upper GoT and the joint of the upper and lower GoT, and shows great consistency (Zhang et al., 2015). Yet its mechanism needs further study.

It has been demonstrated that plastic debris poses a considerable threat by choking and starving marine organisms (Barnes et al., 2009; Bhattacharya et al., 2010; Watts et al., 2014). In addition, microplastics are liable to adsorb pollutants such as persistent organic pollutants and heavy metals from marine environments (Zhang et al., 2015; Brennecke et al., 2016). It has been known that fishery resources in the GoT are plentiful, implicating that humans because the microplastics currently in the GoT may carry plenty of other contaminants and may be ingested by marine organisms and then transferred to higher trophic levels, ultimately posing a threat to human health (Paul-Pont et al., 2016; Pellini et al., 2018). Therefore, the combined effects of microplastics and contaminants in the GoT should not be ignored.

4. Conclusions

Our result shows that plastic pollution is ubiquitous in the GoT, but the microplastic abundance denotes a great spatial variability, as the maximum abundance of microplastics is almost 17-fold higher than the minimum abundance. The average abundance of microplastics in the surface sediments of the GoT is 150.4 ± 86.2 pieces/kg, which is in medium level of plastic contamination contrast to other regions. The data in this study does not yield an accurate correlation between particle size and microplastic content, which may result from the multi-sources sediments and different flow field. As elsewhere, the fibers are the dominate microplastic in the GoT. It can be presumed that the principle source of microplastics in the GoT is municipal sewage discharge base on the shape and component of microplastics. The accurate interpretation of sources of microplastic in the GoT is not clear yet, which need further study in the future.

CRediT authorship contribution statement

Ying Wang: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Formal analysis, Writing - review & editing. **Xinqing Zou:** Conceptualization, Supervision, Funding acquisition, Writing - review & editing. **Cong Peng:** Methodology, Software, Formal analysis. **Shuqing Qiao:** Conceptualization, Resources, Writing - review & editing. **Teng Wang:** Methodology, Formal analysis. **Wenwen Yu:** Conceptualization, Formal analysis. **Somkiat Khokiattiwong:** Resources. **Narumol Kornkanitnan:** Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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