

Influence of monsoon seasonality and tidal cycle on microplastics presence and distribution in the Upper Gulf of Thailand

Haruka Nakano^{a,b,*}, María Belén Alfonso^{a,b}, Suppakarn Jandang^{a,b}, Noppawit Phinchan^b, Suchana Chavanich^{c,d}, Voranop Viyakarn^{c,d}, Atsuhiko Isobe^{a,b}

^a Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan

^b Center for Ocean Plastic Studies, Kyushu University, CU Research Building, Bangkok 10330, Thailand

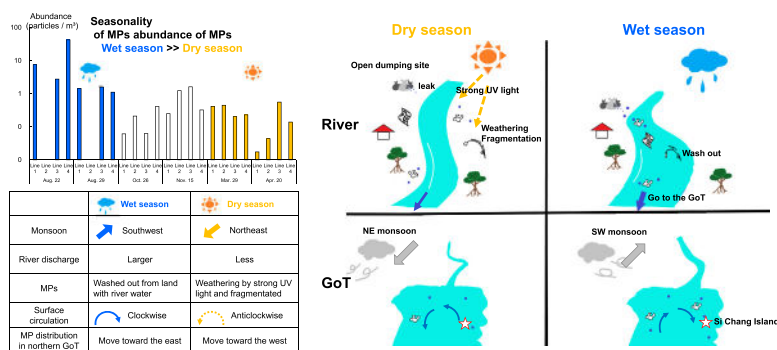
^c Department of Marine Science, Faculty of Science, Chulalongkorn University, Phayathai Road, Pathumwan, Bangkok 10330, Thailand

^d Aquatic Resources Research Institute, Chulalongkorn University, 254, Institute Building No. 3, 9th floor, Wang Mai Sub District Phayathai Road, Patumwan, Bangkok 10330, Thailand

HIGHLIGHTS

- MP survey was conducted in Si Chang Island in the Gulf of Thailand (GoT).
- MP abundance in the wet season was larger than in the dry seasons.
- MP distribution was determined by the surface currents induced by monsoon.
- A system to generate and distribute MPs in GoT was proposed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Ouyang Wei

ABSTRACT

Southeast Asian countries are recognized as significant contributors to the discharge of abundant plastic waste into the ocean. In this study, we conducted neuston net surveys on Si Chang Island of the Gulf of Thailand, a coral reef conservation area, to determine the presence of microplastic (MP) pollution. The survey, conducted during the wet (southwesterly monsoon), transition, and dry seasons (northeasterly monsoon), revealed that the MP abundance was in the range of 0.02–42.46 particles m^{-3} . The precipitation, wind, and current direction induced by monsoons influenced the abundance and distribution of MP, presenting a significant seasonality. The cluster analysis for colors and polymer types of MPs suggested that the origin of plastic particles is diverse. Based on our results, a proposal for the generation, sources, and pathways for MPs in the Gulf of Thailand is presented: 1) plastic wastes exposed to strong UV light during the dry season get fragmented around the river, and 2) heavy rains wash away the particles during the wet season. This proposal is applicable to tropical regions, including the Gulf of Thailand. Therefore, this paper concluded that ocean currents induced by monsoons and the unique climate, resulting in the generation of MPs on land, increase MP presence and distribution in the ocean surrounding Southeast Asia countries. Furthermore, coral reef ecosystems can be particularly threatened by MPs in

* Corresponding author at: Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan.

E-mail address: nakano.hrk@riam.kyushu-u.ac.jp (H. Nakano).

<https://doi.org/10.1016/j.scitotenv.2024.170787>

Received 11 December 2023; Received in revised form 23 January 2024; Accepted 5 February 2024

Available online 12 February 2024

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these areas. So, an increase in MP monitoring on coral ecosystems from Thailand and the world is highly recommended.

1. Introduction

Marine plastic pollution is a global concern involving various stakeholders, such as many economies, policymakers, fishermen, citizens, and scientists. Different estimations suggest that between 4.8 and 1.27 million metric tons (MMT) (Jambeck et al., 2015), 1.15–2.41 MMT (Lebreton et al., 2017) or 0.4–4 MMT (Schmidt et al., 2017) enters to the world's ocean; however, even the emission values from the land have got updated (e.g., 9300 ton year⁻¹ in Thailand; World Bank Group, 2022), most of this plastic waste is undetectable under the current observation framework (i.e., missing plastics problem; e.g., Cózar et al., 2014). In particular, primary and secondary microplastics (MPs) (Andrady, 2011; Cole et al., 2011), which are plastic particles with a size <5 mm resulting from manufacturing and plastic waste fragmentation, respectively, play a key role in global plastic pollution problems. In this sense, several past and undergoing international projects about the microplastic mitigation strategies for aquaculture systems (e.g., the Ocean and Fisheries Working Group of Asia Pacific Economic Cooperation) and global data harmonization projects (e.g., EUROqCHARM, the Ministry of the Environment, Japan, and others), among others, consistently advocate the importance of data collection to fill the gap in the missing plastics problem.

MP pollution is ubiquitous and remains of significant concern because of its uncertain effects on organisms and human health. Plastic particles have been found in a variety of regions like islands in Southeast Asia (e.g., Yuan et al., 2023), the South China Sea (Liu et al., 2023), and even remote regions such as the Antarctic Ocean (Isobe et al., 2017), and the Arctic Ocean (Lusher et al., 2015; Kanhai et al., 2018). In the ocean, MPs can be found in all the compartments, such as the surface water (e.g., the East China Sea by Nakano et al., 2021b), along the water column (e.g., Lenaker et al., 2019), and the seafloor sediments (e.g., Tokyo Bay by Wang et al., 2021), and marine organisms (e.g., zooplankton by Alfonso et al., 2023). Therefore, the continuous evaluation of plastic

pollution is required all over the world.

From previous global MP distribution studies, it is clear that there is still a reduced number of studies for marine environments in South East Asia. In 2014, Eriksen et al. (2014) simulated the global ocean distribution of MPs, but the in-situ data for Eastern Asian countries was missing because of a lack of monitoring data. In 2019, Isobe et al. (2021) analyzed the global distribution of MPs in the ocean, but there was still a significant data gap in Southeast Asia. In recent years, studies were developed in the Gulf of Thailand (GoT), including Bandon Bay (Ruangpanupan et al., 2022) and Chao Phraya River (Oo et al., 2021; Ta and Babel, 2020a, 2020b, 2020c). Besides, in a region where climate variability impacts the environment, knowledge about the seasonality of MP distribution is still necessary. For example, previous studies found that MP abundance in a river and bays relates to precipitation, showing high precipitation resulted in higher MP abundance (in South Korea Eo et al., 2019; in Japan Nakano et al., 2021a), but such knowledge is still lacking.

Furthermore, besides coral bleaching reported in Thailand (e.g., Phongsuwan et al., 2013; Chavanich et al., 2022), plastic pollution can threaten the coral ecosystem, affecting their physical, toxicological, and trophic conditions. For example, plastics covering coral surfaces increase the possibility of disease (Lamb et al., 2018). Around Si Chang Island, located on the northeast coast of the GoT, a project to combat coral bleaching is being implemented by the Department of Marine and Coastal Resources (DMCR) and Chulalongkorn University. Increasing our knowledge about MP presence and distribution in marine environments from the GoT can improve our knowledge of coral conservation strategies and implementations.

Therefore, the aim of this study was to conduct an MP monitoring campaign in Si Chang Island to understand the effect of season (wet, intermediate, and dry seasons) and tidal (neap and spring) conditions on particle characteristics (shapes, colors, and polymer types), abundance and spatial distribution. Also, the potential sources of plastic pollution

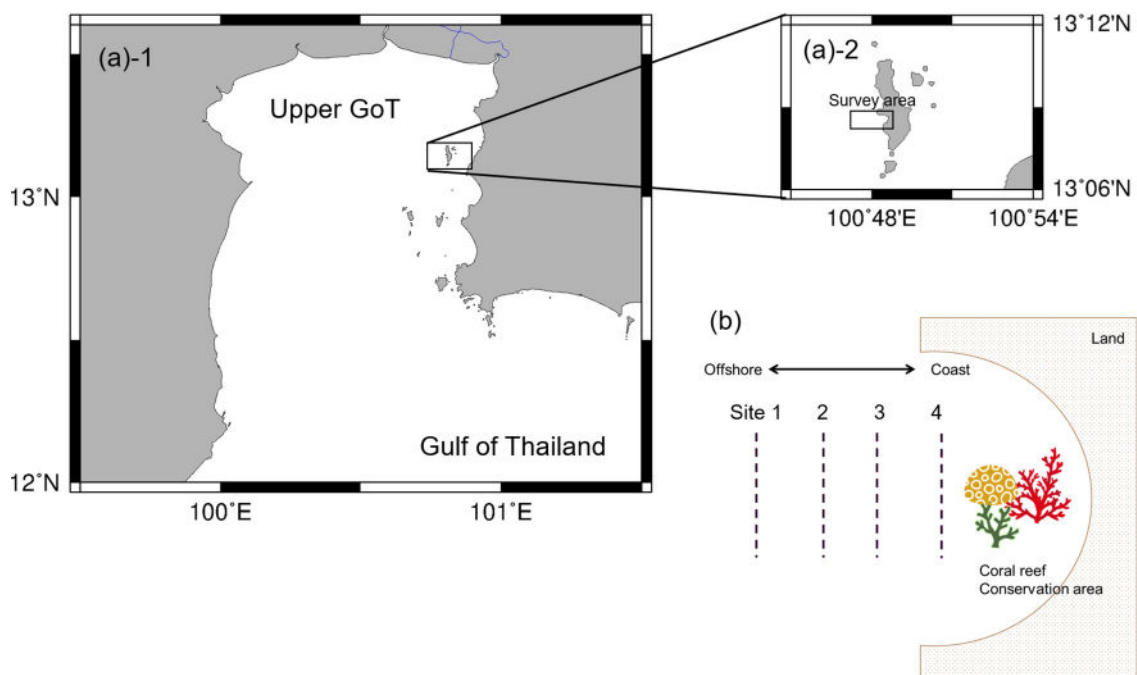


Fig. 1. Geographical location of (a)-1 the northern area of the Gulf of Thailand (upper GoT) and (a)-2 location of Si Chang Island, and (b) Scheme of sampling survey in the four sites.

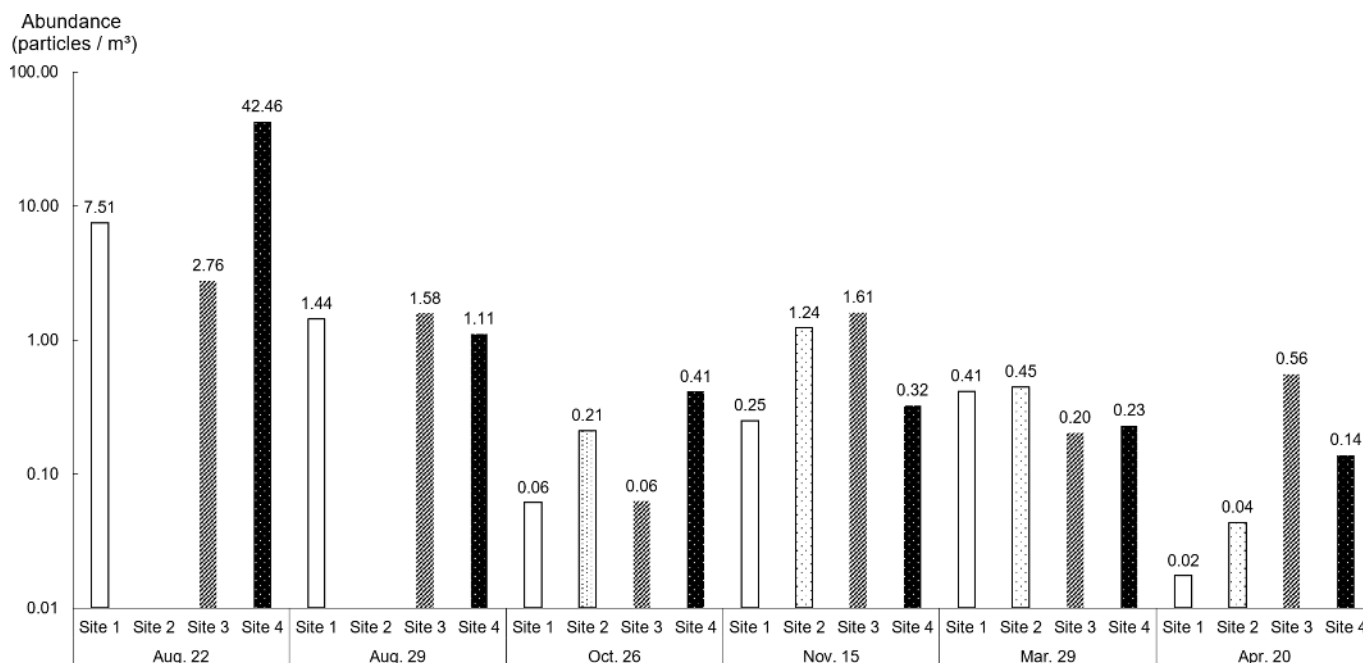


Fig. 2. Abundance of MPs in each station during the study period.

and their pathways were discussed. Finally, based on the obtained data, an analysis of the current situation for MP pollution in marine environments from Eastern Asian countries was made. The obtained results will help to fill the data gap for MP pollution for knowledge-based management decisions.

2. Materials and methods

2.1. Study site and observation

Si Chang Island is located in Chonburi province of Thailand, west of upper GoT. Its population is around 5000, and the area of the island is 36.44 km². Their major industry is tourism. There is a coral reef conservation area around the Island.

In total, six surveys were conducted around Si Chang Island in Thailand (Fig. 1 and Table S1) during the wet (August 2022), transitional (October–November 2022), and dry seasons (March–April 2023). In each season, two campaigns were conducted covering neap and spring tides (Table S2). In each survey, a neuston net with a flowmeter (RIGOSHA, Japan) was towed using a research vessel (*Chula Vessel 2*) along four sites from open waters (Site 1) to the coastal area (Site 4; Fig. 1b) except in August, when only three sites (1, 3 and 4) were sampled due to bad weather conditions. Site 4, nearest to the coast, corresponds to the coral reef conservation area. In August, a neuston net with 350 μm mesh size and 3 m length was used, while a neuston net with 315 μm mesh size and 2 m length was used in the following campaigns. Water volume (m⁻³) was determined with flowmeter data, except during the April survey, when the flowmeter experienced a malfunction; therefore, water volume was calculated with the towing distance using GPS data, the area of the net mouth (0.75 m × 0.75 m), and the proportion of the submerged net mouth area (0.5). The net was towed between 10 and 20 min to avoid net clogging. Then, the net was rinsed with seawater from the outside of the net to concentrate the sample in the cod end, avoiding seawater from getting inside the net mouth, and the samples were stored in a polyvinyl chloride (PVC) container with 4 % formalin. As our target is floating MPs ≥ 350 μm, PVC containers were selected to avoid sample loss/damage in the RV. The selection was based on its high density and low probability of being found floating in seawater following Michida et al. (2019).

2.2. Sample processing and analysis

2.2.1. Sample preparation

Seawater samples were filtered with a stainless sieve (mesh size: 212 μm) and the retained material washed to individual glass beakers. Then, two-step digestion with KOH (50 °C, 72 h) and H₂O₂ (room temperature; 1 h) was conducted in one sample (August 22nd, 2022) to remove the excessive organic material (Alfonso et al., 2021; Tanoiri et al., 2023). The remaining samples did not present a significant amount of organic matter, so they were only sieved and transferred to a clean glass beaker. Finally, each sample was entirely visually checked in a petri dish, and all the potential plastic particles were collected with tweezers in a clean petri dish and dried at room temperature for 8 h (e.g., Nakano et al., 2021a).

2.2.2. Physical characterization

Each particle was inspected and photographed under a stereomicroscope (NSZ-405 J3, SHODENSHA) with a digital camera (DN3V-500, SHODENSHA). Each particle was classified according to its shape, size, and color following GESAMP (2019). The maximum Feret's diameter of each particle was measured using the Measure Pro Light software (SHODENSHA). Particles were classified according to their color and six shape categories (primary MPs: pellets; secondary MPs: fragments, foam, film, line, and fiber) (GESAMP, 2019).

2.2.3. FTIR analysis

The plastic polymer composition of the potential particles was measured using the attenuated total reflection method for Fourier transform infrared spectrometry (IRTracer-100, SHIMADZU). The background and sample spectra were obtained after ten times scanning with a resolution of 4 cm⁻¹ and a wavenumber of 400–4000 cm⁻¹. The hit quality index (HQI) was used to verify the matching rate of the measured spectra to a plastic polymer and UV-damaged polymer data libraries provided by Shimadzu. Those spectra with an HQI > 800 were accepted, and of the candidate particles, 78 % were identified as plastic. For the data analysis, we only used the particles that were identified as plastics. Examples of the registered plastic polymer spectra are shown in the supplementary material (Fig. S1).

Table 1
Microplastic abundance (pieces m^{-3}) comparison in East and Southeast Asia.

	Region	Method	Abundance (pieces m^{-3})	Reference
River	Chao Phraya River, Thailand	Manta trawl	28–140 ^a	Ta and Babel (2020a)
	Estuary of Chao Phraya River, Thailand	Manta trawl	48 ± 8	Ta and Babel (2020b)
	Chao Phraya River, Thailand	Manta trawl	79	Ta and Babel (2020c)
	Estuary of Chao Phraya River, Thailand	Manta trawl	3.11–5.16	Oo et al. (2021)
Gulf of Thailand	Cisadane River, Indonesia	Grab sampling	13.33–113.33	Sulistiyowati et al. (2022)
	Bandon Bay, Thailand	Grab sampling	(0–0.63) × 10 ³	Chinfak et al. (2021)
	Bandon Bay, Thailand	Manta trawl	0.04–0.33	Ruangpanupan et al. (2022)
	Si Chang Island, Thailand	Neuston net	0.02–42.46	This study
South China Sea	Kuala Nerus and Kuantan	Grab sampling	Not applicable	Khalik et al. (2018)
	Terengganu estuary, Malaysia	Water pump	1687–1900	Taha et al. (2021)
	Off Indo-China peninsula	Water pump	34.2–1816	Cui et al. (2022)
	Nansha Islands	Neuston net	0.01–0.15	Tan et al. (2020)
Java Sea	Benoa Bay, Indonesia	Manta trawl	0.11–1.88	Suteja et al. (2021)
East Asian seas	Tokyo Bay, Japan	Neuston net	0.04–17.75	Nakano et al. (2021a)
	Around Japan	Neuston net	0.03–491	Isobe et al. (2015)

^a Data was corrected for MPs > 300 μm .

2.3. Data analysis

The numbers of particles were converted into the abundance data (particles m^{-3}) by using the water volume. A one-way ANOVA with Welch's test, and Shirley-Williams test was conducted to confirm the abundance depending on the different sampling dates. Also, a hierarchical cluster analysis was conducted to examine the similarities of MP characteristics obtained in each survey. The statistical analysis was conducted using BellCurve for Excel (version 4.02; Social Survey Research Information Co., Ltd.). Also, to determine the pollution status around the island and to examine the importance of each sampling station, the Polymer Hazard Index (PHI), and the Pollution Load Index (PLI) indexes (e.g., Kabir et al., 2021) were calculated, and their results are shown in the supplemental information (Figs. S2 to S5).

2.4. QA/QC and limit of detection (LOD)

To avoid contamination of samples, all glassware material was washed in an ultrasonicator (digital ultrasonic cleaner, GT SONIC) and rinsed with milli-Q water (PURELAB flex 3, ELGA). Laboratory experiments were conducted under a clean bench (ADS-UG, Yamato Science). Also, a cotton lab coat specialized for a clean room (avoids particle release) and nitrile gloves were used to avoid contamination. Makeup is not allowed in the laboratory.

A neuston net with a recommended mesh size of 350 μm (Michida et al., 2019) was used, so the particles >350 μm were reported, leading to an underestimation of the number of filaments (fiber and line) compared to grab sampling. The target particles in this study were lighter plastics than seawater; therefore, PVC sampling bottles were applicable. Particles having the same polymer types (e.g., unsaturated polyester) as those from the vessel painting were excluded from the analysis.

A negative control (blank test) conducted under the same procedure as the sample preparation confirmed the absence of contamination of the target particles (Table S3). Also, a previous positive control (recovery test) showed that 97 % of particles were collected using the proposed protocol (Nakano et al., 2021a).

3. Results and discussion

3.1. MPs in Si Chang Island

3.1.1. Abundance

The information for the water volume and the abundance of MPs for each station and date were summarized in Fig. 2 and Table S2. The highest average value registered was 17.58 ± 21.68 particles m^{-3} on Aug. 22nd, followed by 1.38 ± 0.24 particles m^{-3} on Aug. 29th, whereas

the lowest values were 0.19 ± 0.17 particles m^{-3} on Oct. 26th and 0.19 ± 0.25 particles m^{-3} on Apr. 20th. The average abundance showed a significant difference depending on the season ($p < 0.01$ by Welch's ANOVA, see Table S4). Also, from Fig. 2, it was found that the abundance of MPs on site 3 was larger, but not significantly, than offshore sites 1 and 2 on Nov. 15th and Apr. 20th. Also, the abundance in site 4 was larger, but not significant, than in other sites on Aug. 22nd and Oct. 26th. These results suggest that coastal sites can sometimes present higher MPs abundance than offshore areas.

The abundance of MPs in Si Chang Island was compared with those reported in Southeast and East Asian areas (Table 1). The microplastic abundance in the station nearest to the coast (Site 4, Aug. 22nd) was 42.46 pieces m^{-3} , similar to those reported in the Chao Phraya River (Ta and Babel, 2020a), (Ta and Babel, 2020b) and its estuary (Oo et al., 2021) but higher than those reported in Bandon Bay, in the west of GoT (Ruangpanupan et al., 2022). However, the lowest abundance of 0.02 pieces m^{-3} of site 1, which is the most offshore point, on Apr. 20th, was lower than the previous results reported in Thailand. Due to seasonal and site-specific variations in MP abundance, future monitoring on this island should span different seasons and locations along the offshore-coastal line for a more comprehensive assessment.

To the best of our knowledge, only seven studies have been published around the GoT using a variety of sampling methods to monitor the presence of floating MPs (Table 1; Chinfak et al., 2021; Oo et al., 2021; Ruangpanupan et al., 2022; Ta and Babel, 2020a, 2020b, 2020c). Despite the use of neuston nets for the MP survey, the sampling methods still presented some discrepancies among studies that hindered the comparison of results, including the use of high towing speed than recommended in the monitoring guidelines (GESAMP 2019; Michida et al., 2019), and the report of MP sizes below the net pore size (over-estimation). Therefore, more studies are still needed in the future, focusing on using harmonized methodologies to understand the space and time distribution of floating MPs in GoT.

When MP abundance values for Si Chang Island are compared to studies in East and Southeast Asian countries (Table 1), similar values were registered in the South China Sea and the Java Sea (Suteja et al., 2021; Tan et al., 2020), with the exception of Aug. 22nd when the abundance increased reaching similar values to those reported in Tokyo Bay (Nakano et al., 2021a). Despite the island being located in a region highly polluted by mismanaged plastic waste (Jambeck et al., 2015), the abundance of MPs on Si Chang Island was lower than those values in East Asian seas (Isobe et al., 2015). Furthermore, the MP abundance in Si Chang Island was lower than those reported in previous studies using a grab sampler or a water pump as monitoring methods (e.g., Bandon Bay in Thailand: Chinfak et al., 2021; Off Indochina peninsula: Cui et al., 2022; Terengganu estuary in Malaysia: Taha et al., 2021). This huge abundance discrepancy was caused by the fact that these studies

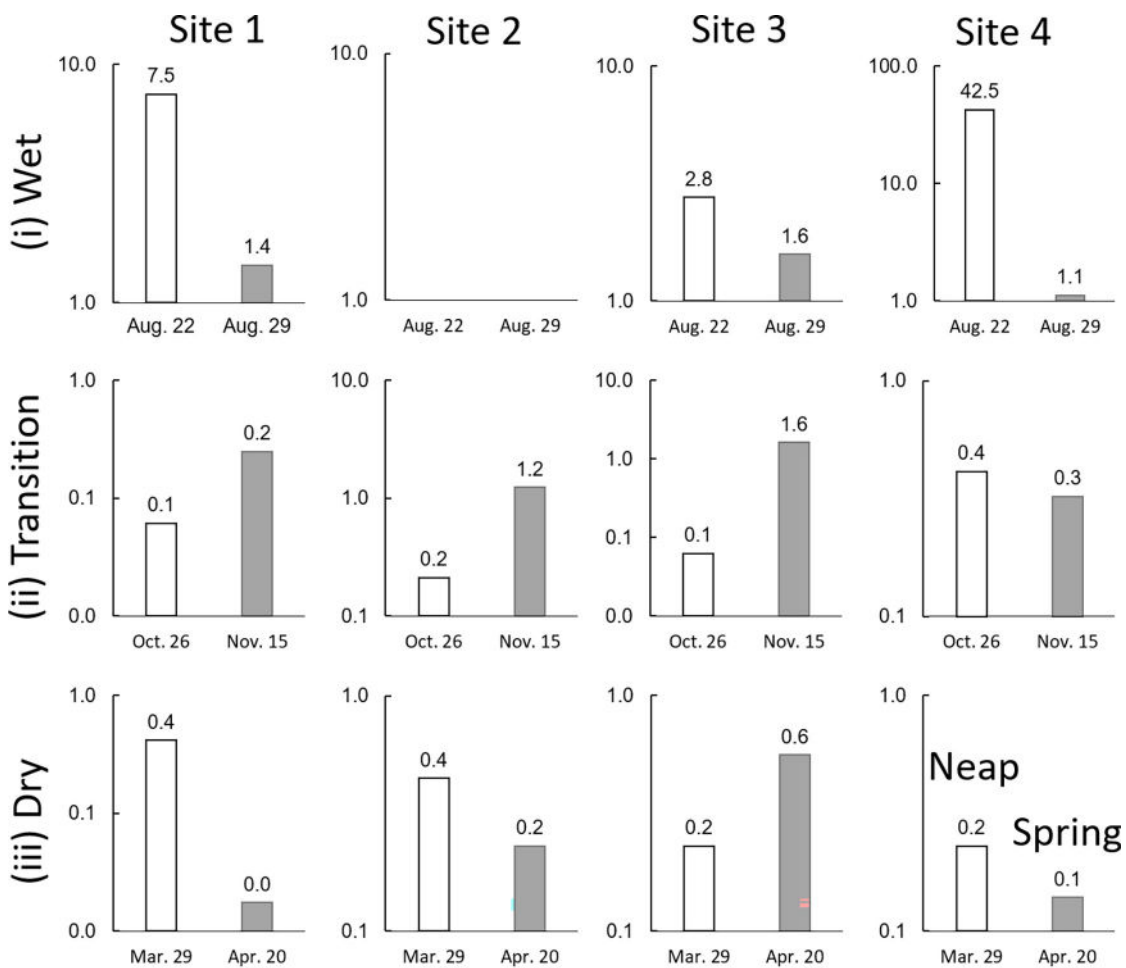


Fig. 3. Abundance of MPs during spring and neap tides in Si Chang Island.

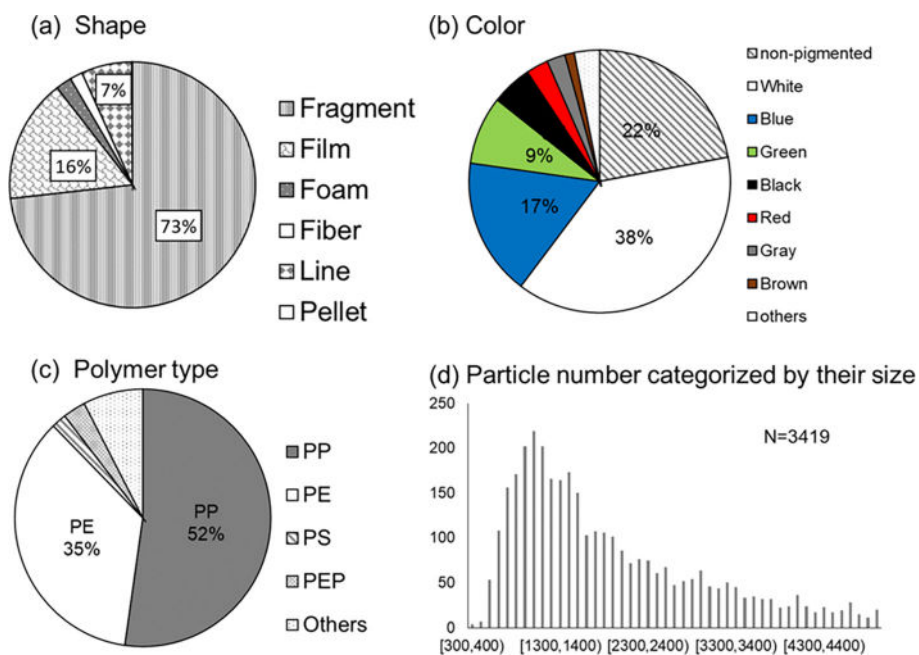


Fig. 4. Characteristics of total MPs collected by this campaign.

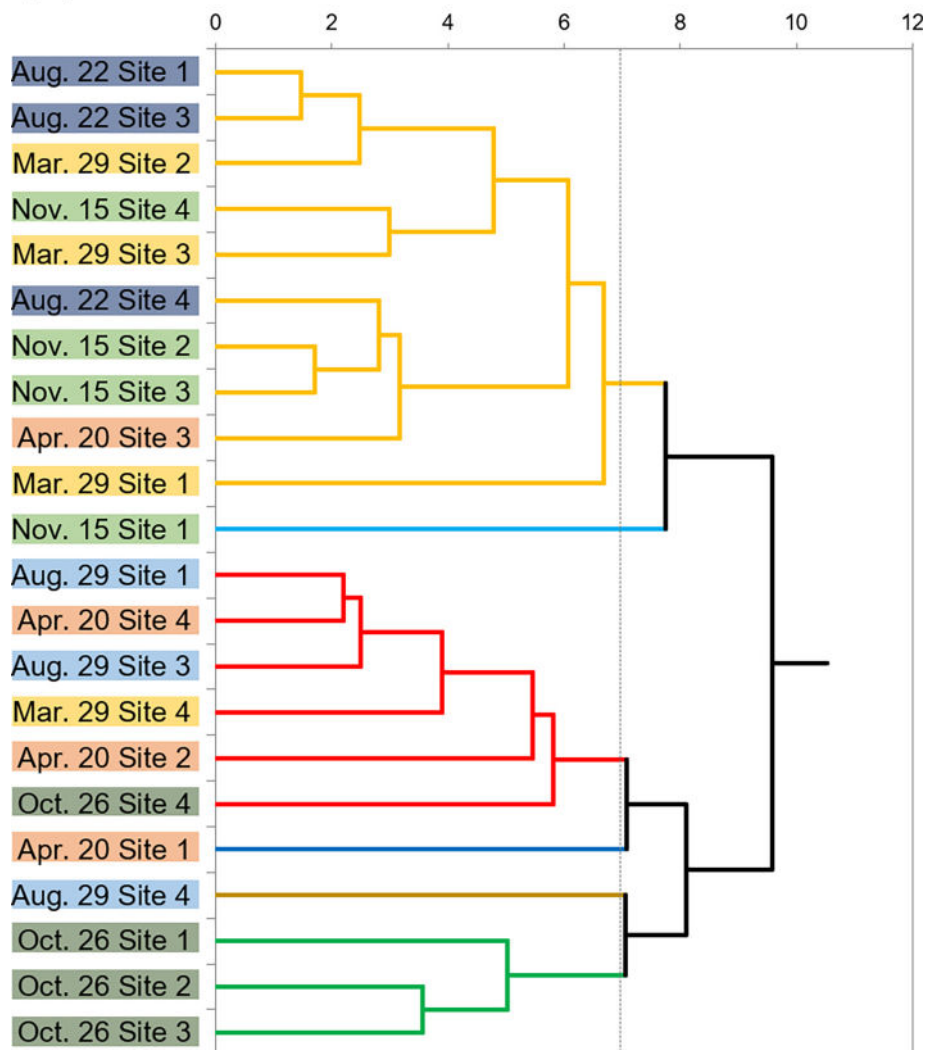
(a) Color

Fig. 5a. The difference in MP characteristics and tendency in the similarity for the different seasons can be caused by the different plastic pollution sources even during the same sampling period, suggesting that the land of Si Chang Island is not only the source of MPs in our sampling site.

included fibers and lines and included particles below 300 μm , which were not possible to collect in this study if we consider mesh selectivity (Tokai et al., 2021).

3.1.2. Seasonality and tidal effect on MPs

The abundance of MPs decreased from the wet (Aug. 22) to dry (Apr. 20) seasons (Fig. 2 and see Table S4, and $p < 0.01$ by Welch's ANOVA). In particular, the abundance of MPs in Site 4 on August 22 was one to two orders of magnitude larger than the other values. Even excluding Site 4 on August 22 from the analyses, the abundance of MPs in Sites 1 and 3 on the same day was larger than those obtained on the following dates. Furthermore, during the sampling, the neuston net collected many plant seeds with MPs floating around Site 4 (Fig. S6), suggesting that the floating debris would have a common origin from the land. A previous study in Si Chang Island registered a salinity difference between dry and wet seasons (wet season: 29.2 on 17 July 2011; dry season: 32.8 on 19 February 2011; Somboonna et al., 2012 and 2019), which was explained by the influence of freshwater from the river during the wet season. These results are in accordance with a previous study that found a positive relation between the amount of precipitation and the abundance of MPs (Eo et al., 2019). The heavy rains (hence, larger river discharge) during the wet season would lead to the runoff of

terrestrial debris, increasing riverine MP emissions to the ocean. Therefore, MP abundance in Si Chang Island has a remarkable seasonality, with larger (smaller) values in the wet (dry) season.

In addition, wind direction during the monsoon could contribute to increasing the number of floating objects in the upper GoT. The southwesterly monsoon prevails from April to September (wet season). Meanwhile, in October, the monsoon wind direction gets gradually reversed (transition season) to finally be dominated by northeasterly winds from November to March (dry season). Thereby, floating objects are likely to be trapped around the upper GoT, including the areas close to Si Chang Island, especially in the wet season. Also, the surface ocean circulation induced by the monsoon winds plays a significant role in determining the floating object distributions. In the upper GoT, the clockwise (anti-clockwise) surface ocean circulation is driven by the southwesterly (northeasterly) monsoon winds during the wet (dry) season (Anutaliya, 2023). The floating plastic litter could be carried by this clockwise circulation eastward towards Si Chang Island, and thus, the amount of floating MPs increased in the wet season. Meanwhile, the anticlockwise surface circulation will wash away the MPs floating around this island to the west. This is in accordance with previous studies in the Red Sea, where it was reported that plastic litter was effectively transported by offshore-ward surface currents driven during

(b) polymer type

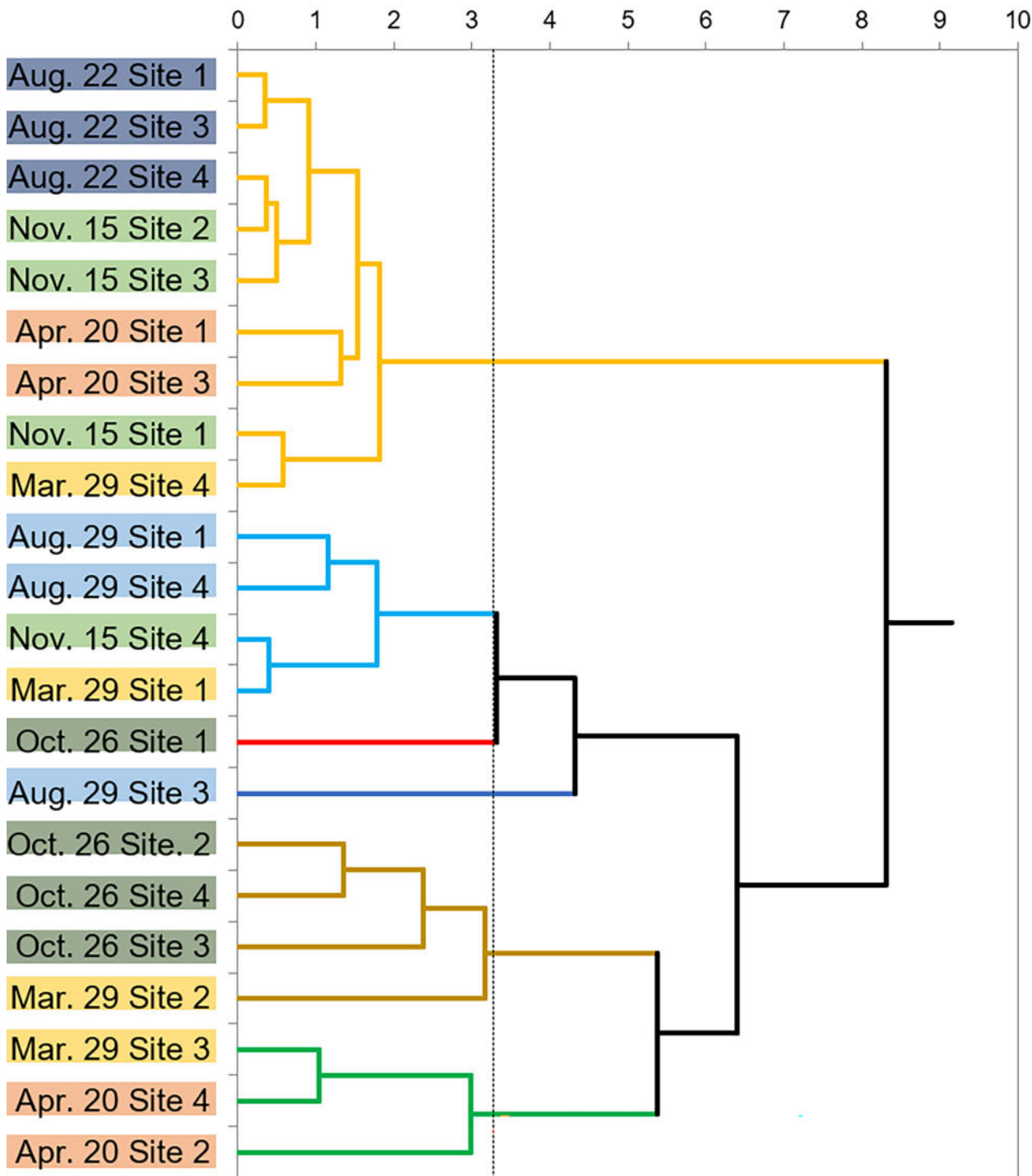


Fig. 5b. Result of cluster analysis. The dashed line serves as a discerning threshold, demarcating six distinct categories (continued). The same colored bar means that the sites belong to are in the same category, indicating a high degree of similarity.

the dry (winter) monsoon season compared with the wet (summer) monsoon season when the onshore-ward winds (hence, surface currents) prevail (Martin et al., 2019). Therefore, we concluded that the precipitation seasonality and the wind and current directions during the monsoon affect the abundance of MPs around Si Chang Island.

Regarding the fortnightly tidal cycle (neap and spring tides), the abundance of MPs in neap tides was larger than that in the spring tides except for Site 3 in the dry season (Fig. 3); the opposite tendency

appeared in the transition season except for Site 4. The abundance tendency in the wet and dry seasons was controversial compared with the previous report (Sadri and Thompson, 2014), where the MP abundance was larger in spring tides than in the neap tides. This controversial tendency can be explained by the tidal currents' complexity that makes MP discharge from or into the rivers (e.g., Wolanski, 2007). Hence, although the survey results obtained around Si Chang Island might suggest the importance of MP abundance varying with tidal cycles, we

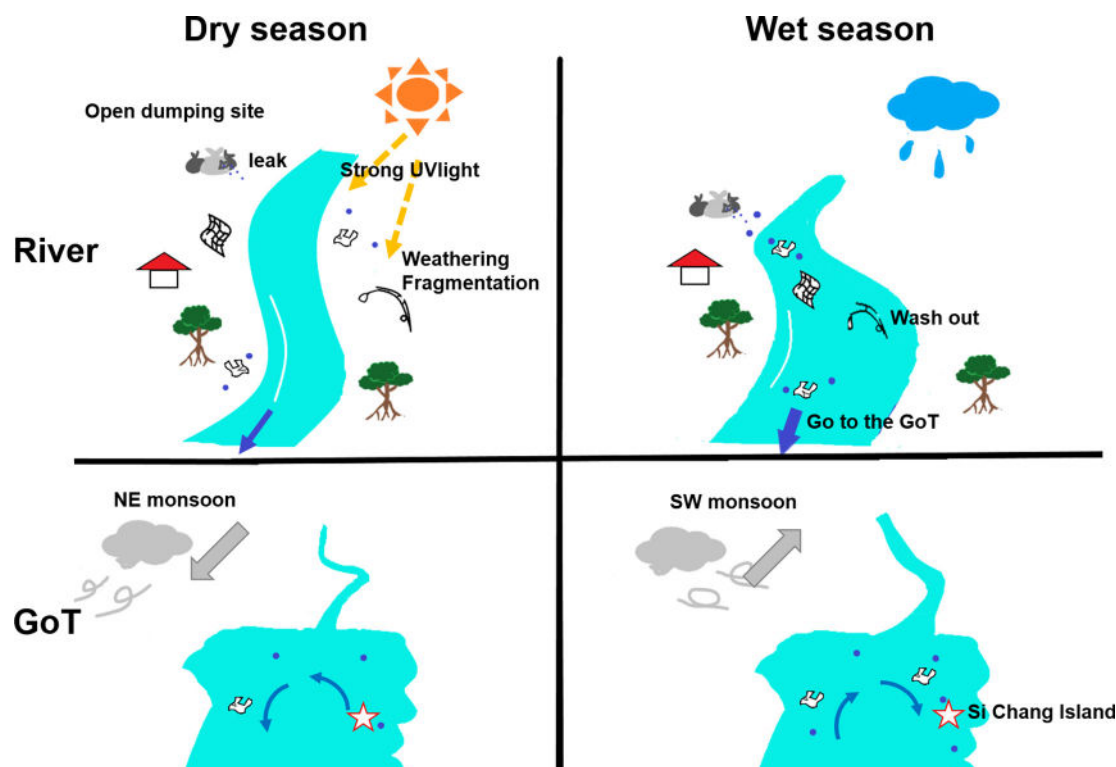


Fig. 6. Schematic figure of MP generation, source, and pathway in the GoT. Thin blue arrows in the lower panel indicate the direction of surface current circulation.

could not draw a firm conclusion from the survey results in the GoT.

3.2. Microplastics size, shape, color, and polymer types

Regarding MP shapes, the most dominant type were fragments (73 %), followed by films (16 %) and lines (7 %) (Fig. 4). In detail, the fragments were dominant except for the spring tide in transition seasons, when films prevailed (Fig. S7). The difference in the dominant shape, such as fragments around Si Chang Island and fibers in Bandon Bay (Chinfak et al., 2021), was attributed to the sampling method, considering the mesh selectivity (Tokai et al., 2021). Focusing on the color of MPs, we found that white was predominant (38 %), followed by blue (17 %) (Fig. 4). In the spring tide of the transition season, black MPs took the second position (Fig. S7). The dominant color of MPs in this study is the same as those in Bandon Bay (clear, white, green, blue, and red; Ruangpanupan et al., 2022). The dominant polymer types were polypropylene (PP; 52 %) and polyethylene (PE; 35 %) (Fig. 4 and Table S5), showing the same dominant polymer type as Ruangpanupan et al. (2022). No PVC particles were registered in any sample, which supports the lack of contamination due to the use of PVC containers. Finally, regarding the size range distribution, there was a predominance of 1000–1100 μm MPs (Fig. 4). This predominance range was in accordance with Isobe et al. (2017).

To compare MP characteristics in each station and each sampling period, the proportion of each color and polymer type shown in Fig. S7 was used as an input value of the cluster analysis (Fig. 5a). Six clusters were obtained, coinciding with the number of surveys. In terms of colors and polymer types of MPs, samples each month presented high similarities in the wet season. For instance, on Aug. 22, a high similarity was found in color and polymer type at every station (all stations in the same cluster). Although Site 4 (Site 3) was in a different cluster in terms of color (polymer type) on August 29, they were grouped in the same upper cluster. On the contrary, the similarity was not so clear for the MP characteristics collected in the dry season (March and April), with Site 4 categorized in a cluster different from March 29. Such a decrease in the

similarity tendency appeared on April 20 as well; Sites 2 and 4 were located far from Sites 1 and 3 in terms of polymer types. The difference in MP characteristics and tendency in the similarity for the different seasons can be caused by the different plastic pollution sources even during the same sampling period, suggesting that the land of Si Chang Island is not only the source of MPs in our sampling site (Fig. 5b).

3.3. Generation, sources, and pathways of MPs in the Gulf of Thailand

From this study in Si Chang Island it stands out that 1) the abundance of MPs had a seasonality, decreasing from the wet season to the dry season, 2) the similarity of MP characteristics was higher during the wet season and lower during the dry season, and 3) a significant amount of plant seeds originated from land were collected in conjunction with a high number of MPs in Site 4 on Aug. 22 survey. It is considered that MPs are generated because of the weathering due to the ultraviolet (UV) light exposure in conjunction with physical stresses such as wave effects on beaches (Efimova et al., 2018). However, if MP presence were only influenced by beach generation, we would not observe significant seasonal variation, given the consistent UV radiation and physical stresses in subtropical regions throughout the year. Therefore, the rise in MP abundance is better explained by the impact of winds, currents induced by monsoons, and increased runoff of MPs from the land. Future studies incorporating measurements of plastic polymer damage will further substantiate this hypothesis.

Based on our results, a system of MP generation, source, and pathways in the GoT is presented in Fig. 6. During the dry season in Southeast Asian countries, plastic waste littered on land is continuously exposed to strong UV radiation, rapidly degrading the plastic waste and enhancing MP generation. The newly generated MPs are accumulated in the terrestrial areas and transported to the oceans via rivers, with a significant runoff increment during the wet season, when heavy rains such as subtropical squalls wash off intermittently plastic wastes, including MPs. In addition, the surface ocean circulation induced by the north-easterly monsoon winds removes the floating plastic litter westward

(Fig. 6), and the currents induced by southwesterly monsoon winds during the wet season accumulate around Si Chang Island.

Actually, there are many rivers in Southeast Asian countries where plastic waste is wrongly discarded, and so a large number of MPs were found (e.g., Chao Phraya River: Ta and Babel, 2020a, 2020b; Cisadane River, Indonesia: Sulistyowati et al., 2022). These previous studies suggested that MPs are not only generated in a swash zone (beach) but also in a terrestrial area. In addition, the possibility of waste leakage from open dumping sites, often present in Southeast Asian countries, would be non-negligible. A numerical simulation study showed that 95 % of plastic waste has been lost in terrestrial areas (Isobe and Iwasaki, 2022). Such a scenario in which the lost plastic litter accumulates in the vicinity of the rivers, degrades into MPs, and thereafter enters into the ocean via rivers can be widely adopted in Southeast Asian countries.

4. Conclusion

Southeast Asian nations were identified among the top ten contributors to plastic waste in the oceans (e.g., Jambeck et al., 2015). Nevertheless, the estimated figures for plastic litter emission need updating (e.g., World Bank Group, 2022). It is imperative that these countries implement mitigation plans to curb plastic pollution and align with Sustainable Development Goal 14. However, monitoring efforts for assessing marine plastic pollution, particularly microplastics, remain insufficient.

In conclusion, our study contributes valuable insights to the understanding of MP dynamics in the Gulf of Thailand, highlighting the interconnectedness of terrestrial and marine environments in the proliferation of plastic pollution. The proposed model offers a holistic perspective on the intricate processes governing MP presence in the region, emphasizing the importance of multifaceted strategies for mitigating plastic pollution in Southeast Asian countries.

Furthermore, Si Chang Island is one of Thailand's conservation sites for coral reef ecosystems. The coral reef present in Si Chang Island is a new reef community with the potential to grow and develop into a more extensive ecosystem. Based on our findings about MP presence and distribution in Si Chang Island and considering that corals can catch MPs instead of zooxanthellae (Rotjan et al., 2019), a deterioration of their trophic state on this island could be expected. Therefore, an increase in MP monitoring of coral ecosystems from Thailand and the world is highly recommended to evaluate the effects of plastic pollution.

CRedit authorship contribution statement

Haruka Nakano: Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **María Belén Alfonso:** Writing – review & editing, Methodology, Investigation. **Suppakorn Jandang:** Writing – review & editing, Investigation. **Noppawit Phinchan:** Writing – review & editing, Data curation. **Suchana Chavanich:** Writing – review & editing, Supervision, Resources, Funding acquisition. **Voranop Viyakarn:** Writing – review & editing, Supervision, Resources, Funding acquisition. **Atsuhiko Isobe:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgments

This research was mainly supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS), Japan, in collaboration between the Japan Science and Technology Agency (JST, JPMJSA1901) and Japan International Cooperation Agency (JICA). Also, this research was partly supported by JSPS KAKENHI Grant Number JP22K21328, JP23K17048, JP23K17030, and the Research Start Program of Kyushu University. We appreciate Dr. Shingo Takeda, the captain, and the technical staff members of *Chula Vessel 2* for their support during the field surveys.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2024.170787>.

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