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The first occurrence, spatial distribution and characteristics of microplastic particles in sediments from Banten Bay, Indonesia

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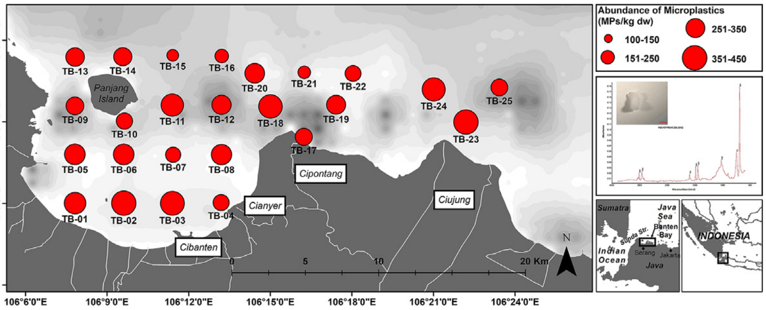
HIGHLIGHTS

- Microplastics were investigated in a shallow and semi enclosed bay of the Banten Bay, Indonesia.
- Mainland distance and river outflows affecting to microplastics distribution.
- Expanded Polystyrene (EPS) was the most abundant microplastics found.
- The high abundance of EPS confirmed the aggregation and biofouling mechanism.

GRAPHICAL ABSTRACT



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ABSTRACT

Microplastics (MPs) are recognized as an emerging issue worldwide, including Indonesia. Due to the limited of data available regarding MPs pollution in Indonesian waters, we investigated the occurrence, spatial distribution, characteristics, and potential ecological impacts of MPs in sediments from 25 stations in the Banten Bay, a shallow and semi enclosed bay located on the northwestern coast of Java, Indonesia. The bay has experienced very high population pressure due to increasing coastal development in the last decade. MPs were extracted by flotation methods, observed under a stereomicroscope, and identified by FTIR imaging. This study showed that MPs pollution is prevalent in the Banten Bay, where all sediments contained MPs with an average concentration of 267 ± 98 particles/kg dw sediment. The most common shape, size, and polymer type were foam (38% of the observed MPs), size between 500 and 1000 µm (>50%), and extended polystyrene, respectively. The particles were found to be more highly distributed in the stations with fine sediment grain sizes and in locations near the river mouth of the island than in areas offshore, which suggests that the impact of the MPs currently in the sediments might be harmful to the benthic community and potentially increase the magnitude into the pelagic community. Moreover, the river effluent is suggested as a pathway for plastic pollution to the Banten Bay.

1. Introduction

Plastic marine debris is recognized as an emerging issue in oceans and must be addressed through an intergovernmental action framework (Gregory, 2009; Barnes et al., 2009). Once

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introduced into marine ecosystems, plastic polymers are degraded over a time span of several hundred years (UNEP, 2016; Löhr et al., 2017; Schulz et al., 2017; Iwasaki et al., 2017) and lose their structural rigidity due to physical, chemical and biological processes (Browne et al., 2008). These processes degrade plastic into microscopic sizes smaller than 5 mm (Thompson et al., 2004), which are called microplastics (MPs) (Barnes et al., 2009).

In oceans, the distribution of MPs is affected by their size, shape and density (Iwasaki et al., 2017, Zhang, 2017). MPs with a density lower than seawater will be in the surface water, while MPs with a higher density will subsequently sink to the seafloor (Kaiser et al., 2017). However, a previous study has shown that aggregation and fouling processes affect the ability of low-density MPs, such as styrofoam, to reach the seafloor (Long et al., 2015). In addition, the size and shape of MPs mimic plankton; therefore, MPs can be easily ingested and negatively affect planktivorous biota (Lehtiniemi et al., 2018; Setälä et al., 2014). Moreover, benthic biota in the sediment, and pelagic organisms that live in the water column are also affected (Wright et al., 2013). Various effects will affect not only the aquatic ecosystems, coastal fisheries, and aquaculture, but also human health through the consumption of MPs-contaminated seafood (Lusher et al., 2017a,b; Carbery et al., 2018; Barboza et al., 2018; Hantoro et al., 2019). Without any prevention strategies, MPs have already entered the marine ecosystems locally and threaten to spread globally to other regions of sea (Horton and Dixon, 2018; Lusher et al., 2015).

Establishing comprehensive data on plastic pollution in different location and various environmental matrices particularly in marine sediment in Indonesia is needed. At this moment, several studies have conducted to estimates plastic pollution in Indonesian seas not only based on modeling (Rochman et al., 2015; Cordova and Wahyudi, 2016; Syakti et al., 2017; Sur et al., 2018; Cordova and Hernawan, 2018; Syakti et al., 2018; Handyman et al., 2018; Khoironi et al., 2018; Bangun et al., 2018; Lestari and Trihadiningrum, 2019; Khoironi et al., 2019; Cordova et al., 2019; Yona et al., 2019; Lubis et al., 2019; Hastuti et al., 2019; Alam et al., 2019). Moreover, another study also reported that the Southeast Asia region (mainly Indonesia and Thailand) was the main origin of more than 75% of labeled stranded debris on Alphonse Island, the Seychelles (Duhec et al., 2015). However, the data for plastic pollution particularly microplastics in marine sediment are still insufficient and the investigations remain challenging due to limited equipment and large marine ecosystem of Indonesian Seas. A part from previous study, only 25% of plastic studies was determined from marine sediment and one study from river sediment in Indonesian seas compared with other region worldwide (Mohamed Nor and Obbard, 2014; Auta et al., 2017; Mistri et al., 2017; Peng et al., 2018; Wang et al., 2019).

Through this study, we investigated the current conditions of plastic pollution, particularly MPs, in the middle part of Indonesia with high marine biodiversity, Banten Bay, as field case study. The bay is a small coastal embayment located on the northern coast of Banten and is 60 km west of Jakarta, the capital of Indonesia (Hoitink and Hoekstra, 2005). The bay is potentially receive large input of domestic waste including plastic through the river as well as from several ports around the bay. Moreover, waste management in the coastal area in Indonesia is very poor, and people generallay prefer to burn, bury or throw waste directly into the rivers (Lestari and Trihadiningrum, 2019). Therefore, related to this potential emerging condition, this study was conducted to investigate the composition, distribution and characteristics of MPs in the sediments and to search their relationship with sediment characteristics and seawater depth.

2. Materials and methods

2.1. Sampling area and sample collection

Samples were collected from the Banten Bay and its surrounding at water depths ranging from 1 to 28 m in April 2016 (First Transitional Monsoon). During this transitional season, the hydrodynamic condition including current speed and direction in the Banten Bay were unstable because the characteristics of the Banten Bay as semi-enclosed water area and home of approximately ten small islands with special sites for coral reefs and seagrass (Hoitink and Hoekstra, 2005). The water in the bay receives large freshwater inputs through rivers and canals from shrimp ponds, with the primary river is Ciujung River that discharging freshwater to the east part of the bay, the secondary river is Cibanten River and Cikamayung River, both of them was discharging freshwater in the south and south-west part of the bay. In addition, the bay also received freshwater input from others 11 smaller rivers (Booij et al., 2001).

The area for sediment sampling was designed for an initial overview of microplastics in the surface sediments of Banten Bay. A total of 25 composite sediment samples were collected from station TB-01 to TB-25 with sampling coordinates was listed as supplementary information in Table SI. To accommodate statistical analysis, the stations were divided into 7 sections based on different distances to the coastline of Java Island and the influence of river discharge from the Cipontang River and Ciujung River. The sections were BB1 (TB-01 to TB-04), BB2 (TB-05 to TB-08), BB3 (TB-09 to TB-12), BB4 (TB-13 to TB-16), BB5 (TB-17 to TB-19), BB6 (TB-20 to TB-22) and BB7 (TB-23 to TB-25) (Fig. 1).

The sediment samples were collected using Smith-McIntyre grabs three times. The top layer of sediment (approximately 10 cm) from each individual grab sampling was taken using a clean aluminum spoon and well-mixed sediments were combined to form a composite sample. The composite sediment was stored in closed 1 L Nalgene™ bottles, and kept in an ice box during transfer to the laboratory. In the laboratory, the sediment was split into several subsamples for analysis of grain size distribution, and microplastics concentration.

2.2. Sediment preparation

The grain size of the sediment was analyzed based on granulometric methods (Hsieh, 1995). Briefly, subsamples of sediment were taken, dried in an oven for 12 h, T = 80 °C, and weighed. Distillated water were added to the dried sediment (50 g) and were directly homogenized. Afterward, the slurry were wet sieved through a Wentworth series of stainless steel sieves with mesh sizes of 64, 32, 16, 8, 4, 2, 1, 0.5, 0.25, 0.125, 0.063, and 0.004 mm. The remaining particles in each sieve were dried, and their percentages were calculated based on the Wentworth scale (Wentworth, 1922).

Subsample of wet sediment for microplastics analysis were dried in an oven 24 h at 80 °C and kept in the glass jar for further analysis. In addition, a wet/dry factor of sediment which used on final calculation of microplastics were determined. Briefly, 10 g of wet sediment was transferred to a preweighed porcelain cup, weighed (A) and dried in an oven overnight (minimum 12 h) at 105 °C (B). The wet/dry factors were determined by the following formulas: $\frac{Wetweight}{Dryweight} = \frac{A}{B}$.

2.3. Extraction of microplastics

The microplastics were extracted from dried sediments samples based on a modified flotation method (Claessens et al., 2011;

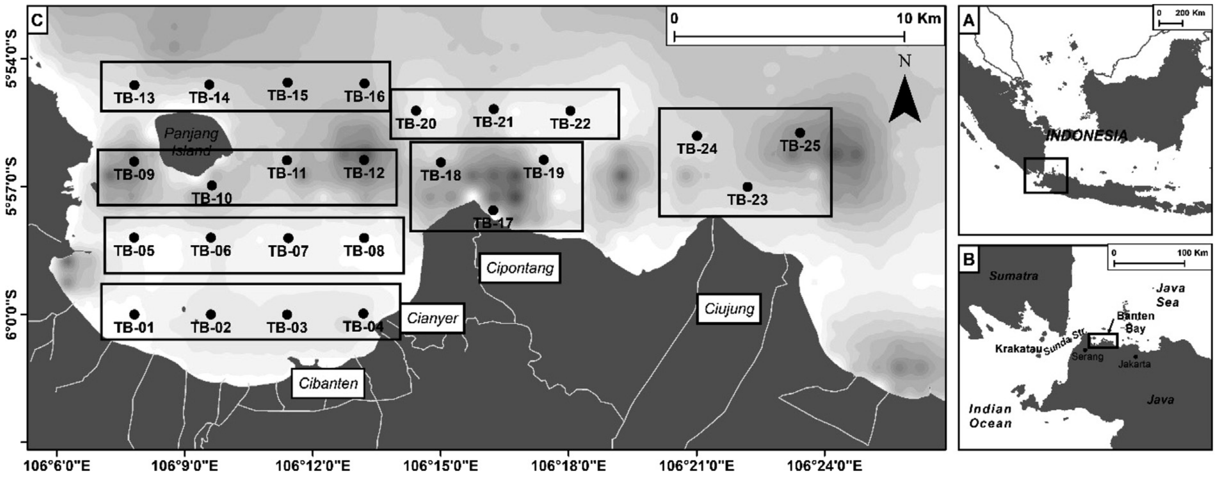

Fig. 1. Map of the Banten Bay and locations of the sampling sites in the Banten Bay, Indonesia. The square boxes represent section: BB1 (TB-01 to TB-04), BB2 (TB-05 to TB-08), BB3 (TB-09 to TB-12), BB4 (TB-13 to TB-16), BB5 (TB-17 to TB-19), BB6 (TB-20 to TB-22) and BB7 (TB-23 to TB-25).

Thompson et al., 2004; Mohamed Nor and Obbard, 2014). Briefly, 250 ml of a filtered NaCl solution (ρ = 1.2 g/mL) was added to 250 g of the dry sediment and stirred with a mechanical shaker at 200 rpm for 10 min. After settling, the supernatant was decanted, and the extraction was repeated twice more. Then, the supernatant containing the MPs was then filtered under vacuum through sterile cellulose nitrate filter paper (Whatman Ø47 mm; pore size 0.45 μm). The filters were placed in covered sterile petri dishes to dry overnight at room temperature (Approx. T = 25 °C) and to prevent air contamination.

In addition, quality control was also applied during the extraction processes and microscopic examination by using cotton laboratory coats, polymer-free gloves and a clean microscopy room, for example (Wesch et al., 2017; Lusher et al., 2017a,b). To observe airborne contamination, clean filter paper was placed near the filtering apparatus and microscope (Torre et al., 2016). Then, the filters from a blank sample and the airborne control were examined under a microscope. No plastic was found on the filters of the air control of the microscopy room, implying that there was no contamination from the glass jars, filtering processes, or microscopy identification.

2.4. Observation and identification of microplastics

All recovered MPs on the filter paper were visualized and counted under a Nikon Eclipse E600 stereo microscope equipped with a digital camera at magnifications up to 100x and were categorized into different shapes and sizes as previous studies (Hidalgo-Ruz et al., 2012). For the shape composition, the counted MPs were divided into four categories, including fragments, fibers, granules and foam (Claessens et al., 2013). The sizes of the MPs were analyzed from pictures using ImageJ software and were categorized into five different size classes (<100, 100–500, 500–1000, 1000–5000, and >5000 μm) (Schneider et al., 2012). To distinguish MPs from other particles, some criteria from Cole et al. (2013) were considered during the investigation with a microscope: (a) particle has no organic or cellular structure, (b) particle has a homogenous color and is not sparkling or shiny, and (c) plastic fibers are unbranched and have no segments. The number of MPs recovered from the samples was expressed in particles/kg dry weight (dw).

Based on image analysis using a microscope, plastic-like particles on the filter paper (n = 85 particles from total 599 particles, or 14%) were randomly selected as representative of the sample for polymer verification using micro fourier-transform infrared microscopy (μ-FTIR) imaging under attenuated total reflection (ATR) mode (Thermo Scientific Nicolet iN10 infrared microscope, Thermo Fisher, USA) (Sun et al., 2018). FTIR used to evaluate polymers due to the capacity to analyze samples effectively (Käppler et al., 2015). FTIR-tested microplastic particles were washed using sterile ethanol (96%). FT-IR was performed on the basis of the experimental configuration of (Käppler et al., 2015; Löder et al., 2015; Löder and Gerdts, 2015), Cordova et al. 2019), 8 cm resolution single reflection mode, 600–3800 cm^{-1} range, and 16 scans per test. The method of defining microplastic polymer categories with ATR FT-IR was performed by analyzing the prominent presence peak (Käppler et al., 2015; Löder et al., 2015); and comparing the spectrum of each sample with the Hummel Polymer and Additives library. Microplastic identification scheme based on a research from Käppler et al. (2015) and Löder et al. (2015) by band region 1174–1087 cm^{-1} (CF_2 stretching vibration), 1400–1480 cm^{-1} (CH_2 bending vibration), 1670–1760 cm^{-1} (C=O stretching vibration), 1740–1800 cm^{-1} (C=O stretching vibration) and at band region 2780–2980 cm^{-1} (stretching vibrations of CH/CH_2/CH_3 groups).

2.5. Statistical analysis

Statistical analyses and graphical data were conducted using RStudio (v. 1.2.5001) with package ggplot2, ggstatsplot, and readxl (RStudio Team, 2019; Wickham, 2016; Patil, 2018; Wickham and Bryan, 2019). All data were tested for their normality and homogeneity. If the data did not follow a normal distribution and homogeneity of variance, therefore, it was analyzed with Kruskal–Wallis non-parametric test. Welch's ANOVA at 0.05 level of significance was applied to investigate differences between abundance of microplastic shapes in different section along the Banten Bay. Non-parametric tests were used to analyze the differences between abundance of microplastic sizes and their total abundance in different section along the Banten Bay. Correlation analysis was performed using package ggstatsplot:ggcorrmat to determine the relationship between the abundance of MPs, seawater depth, and the grain size of sediment (Patil, 2018). All R scipt were presented in Supporting Information.

3. Results and discussion

3.1. Concentration and spatial distribution of microplastics

MPs were found in all sediment samples from the 25 stations (7 group sections), with the number of MPs ranging from 101 to 431 particles/kg dw. The average concentration was 267 ± 98 particles/

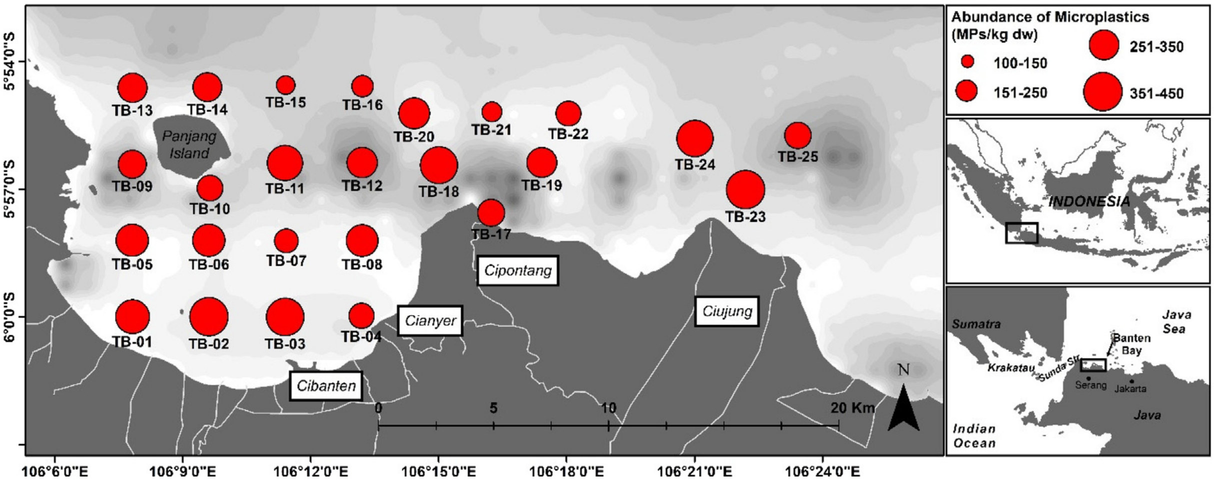

Fig. 2. Abundance and spatial distribution of microplastics (expressed as number of microplastics/kg dry sediment) along the Banten Bay.

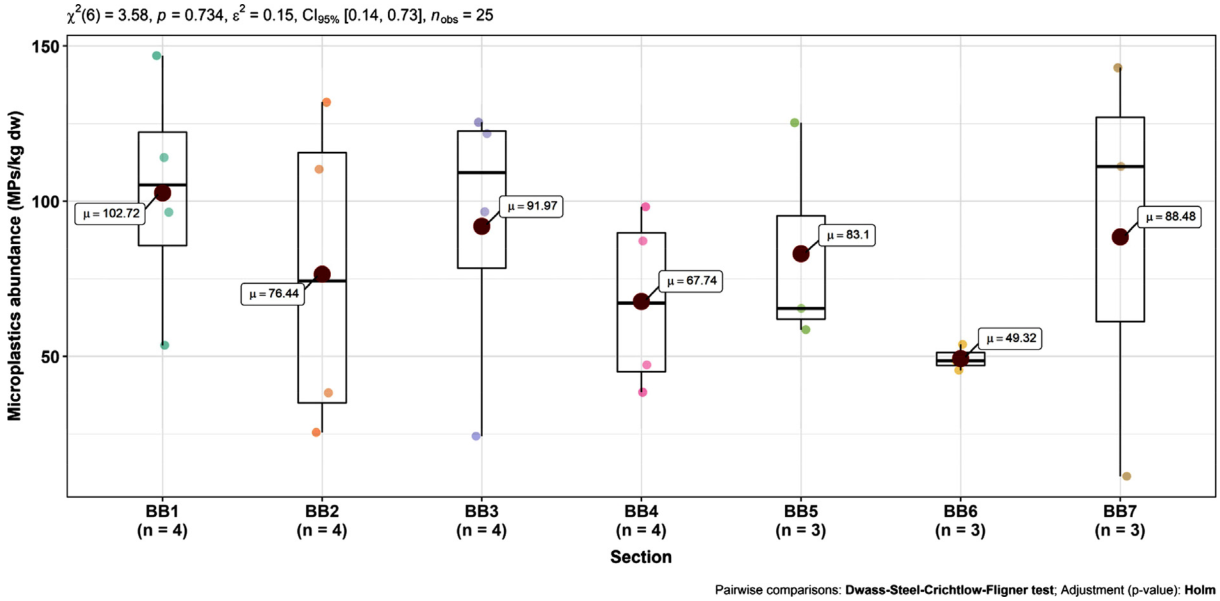

Fig. 3. Comparison between abundance of microplastics in each section from the Banten Bay. No significance was observed. Kruskal–Wallis non-parametric test.

kg dw (Fig. 2). The highest number of MPs was at station 23 (431 particles/kg dw) in section group BB7, which was located toward the river mouth of the Ciujung River; while the lowest particle number was at station 15 (101 particles/kg dw) in section group BB4, the offshore station which directly facing the Java Sea. The abundances of MPs in the sediments were not statistically significant between each section group based on non parametric test (Fig. 3). However, if we observed on the spatial distribution map, there was slightly trend on microplastics abundances, MPs concentration decreased with increasing distance from the river mouth and shore, except for stations TB-04 and TB-17 (Fig. 2). Those finding revealed that distribution of microplastic particles in the sediment of the Banten Bay was homogeneous and did not affected by various distance of group section to the land. Previous study on organic pollution in the Banten Bay found that the concentration of contaminant was elevated from the river entrances into the bay. They suggested that well flushing and significant mixing between contaminated river particle with sea-borne particle was occurred in the Banten Bay (Booij et al., 2001).

The average concentrations of MPs reported in this study were higher than those reported on the North Sea coast, the south pier of Ijmuiden, the Netherlands (Karlsson et al., 2017), the Gulf of Thailand (Matsuguma et al., 2017), the Changjiang estuary (Peng et al., 2017), and the North Sea island of Norderney (Nuelle et al., 2014). However, the mean concentrations of MPs from Banten Bay were also lower than those reported in Tokyo Bay (Matsuguma et al., 2017), Venice lagoon (Vianello et al., 2013), and the Belgian coast (Claessens et al., 2011). The comparison with other location worldwide presented in the Table 1.

3.2. Shapes and sizes of microplastics

The shapes of the MPs present at all sampling stations were foam (n = 182 particles, 30.4%), fragments (n = 159 particles, 26.5%), granules (n = 146, 24.4%), and fibers (n = 112, 18.7%) (Figs. 4 and 5). A one-way between subjects Welch's ANOVA was conducted to investigate whether the distribution of microplastic shapes were vary among group section. There was a not significant variation of fibers, foams and granules in each group section at the $p < 0.05$ level, while fragments was significantly different between section group at the $p < 0.05$ level (Fig. 6). Therefore, for the fragment microplastics, we conducted a post hoc comparisons using

Table 1
Distribution of microplastics in the sediment from other region worldwide.

Country/region	Concentration (particles/kg dry weight)	Polymer	Reference
Arctic, Chukchi Sea and Chunchi Basin	Range: 5.30–68.88	PP, PET, RY	Mu et al., 2019
France, Gulf of Giscay	Mean: 67 ± 76	PP, PE, PS, PVC, PEST	Phuong et al., 2018
Italy, Venice lagoon	Range: 672–2175 Mean: 1445	PE, PP	(Vianello et al., 2013)
Belgian, the Belgian coast (Harbour)	Range: 67–391 Mean: 166.7 ± 92.1	PS, PP, Nylon, PVA, PE	(Claessens et al., 2011)
China, the Changjiang estuary	Mean: 121 ± 9	Rayon, polyester, Acrylic	(Peng et al., 2017)
China, South Yellow Sea	Range: 560–4205	PP, PE, PS, Nylon	(Wang et al., 2019)
China, Sishili Bay	Mean: 499.8 ± 370.1	Rayon, PE, PP, PA, PET, PS, PMMA, PU	Zhang et al., 2019
China, Haihe Estuary	Range: 96.7–333.3 Mean: 216.1 ± 92.1	PE, PP, PS, PVC, PET, CPM	Wu et al., 2019
China, Yondingxinhe Estuary	Range: 56.7–113.3 Mean: 85.0 ± 40.1	PE, PP, PS, PVC, PET, CPM	Wu et al., 2019
Japan, Tokyo Bay	Range: 1845–5385 Mean: 1900	PE, PP	(Matsuguma et al., 2017)
Singapore, Coastal Mangrove	Range: 12.0–62.7 Mean: 36.8 ± 23.6	PE, PP, Nylon, PVC	(Mohamed Nor and Obbard, 2014)
Indonesia, Banten Bay	Range: 101–431 Mean: 267 ± 98	PS, Cellophane, PET, PP, PE	Present study

the Tukey HSD test and indicated that the mean abundance for the fragments in the section group BB4 (M = 32.14, SD = 16.53) was significantly smaller than the section BB7 (M = 114.83, SD = 20.896). Taken together, these results suggest that even in similar degree of location between section group BB4 and BB7, both of them directly facing Java Sea, the river flow from the Ciujung River was effectively boosting the amount of stranded fragments in the seafloor near with river mouth. The present findings seem to be consistent with other research which found that river are the main source of microplastic contamination in the estuary and adjacent areas (Fok and Cheung, 2015; Simon-Sánchez et al., 2019; Zhao et al., 2019; Campanale et al., 2019).

As illustrated in Fig. 4B, most MPs were approx. between 500 and 1000 μm in size (53%), and only 1% of the MPs were >5000 μm. Moreover, the category percentages for microplastic size of <100 μm, 100–500 μm, and 1000–5000 μm were 6%, 17%, and 23%, respectively. Furthermore, results from non-parametric test revealed that there was no significant differences between microplastic's size among section groups (Fig. 7). This results indicated that there was no hotspot area for each size of microplastics in the seabed of the Banten Bay. However, a spatial trend in the MPs distribution with a size fraction of 500–5000 μm was found to be more dominant in the inner water of Banten Bay (Section BB1 to BB3) than in the outer water, and no trend was found for particle sizes >5000 μm.

3.3. Composition of microplastics polymer

Subsamples of seventeen potential particles were selected based on visual observation to determine the type of polymer using μ-FTIR. Of these, 12 fibers were cellophane (CP) (Fig. S2, SI) and synthetic cellulosic fibers, and one particle was identified as diphenyl sulfide, a colorless crystalline material. Related to cellophane, this synthetic particle also was the most common in the sea salt measured in China, up to 43.2% of all identified MPs and in rock/well salts (Yang et al., 2015). The remaining particles were identified as synthetic polymers, including polyester terephthalate (n = 3), polypropylene (n = 1), and polyethylene (n = 1). In addition, 38 particles of the foam type were directly identified based on visual identification and were further corroborated by μ-FTIR as polystyrene (PS).

Fig. 8 shows two examples of the dominant microplastic polymers FTIR spectra (cellophane and polystyrene) found in the Banten Bay sediments. The IR spectrum from the cellophane sample showed a prominent peak at 1061 cm^{-1} and 3338.2 cm^{-1}. Absorption at wavelength 2912.2 cm^{-1} indicating stretching vibrations of CH/CH2/CH3 groups cm^{-1}; and absorption at wavelengths 1428.3 and 1319.2 cm^{-1} indicates methylene scissoring or asymmetrical methyl C—H bending (Fotopoulou and Karapanagioti, 2015, Käppler et al., 2016, Löder et al., 2015, Syakti et al., 2017). Sample of polystyrene particle shows prominent peak at 1452.9 and 1494.1 cm^{-1} symbolize aromatic C—H bond stretching vibrations (Fotopoulou and Karapanagioti, 2015); at wavenumber 2923 cm^{-1} indicate C—H stretching, symmetrical vibrations, and asymmetrical stretching (Fotopoulou and Karapanagioti, 2015, Käppler et al., 2016, Löder et al., 2015); and peak at wavenumber 3062 and 3029.3 cm^{-1} correspond aromatic C—H stretching vibrations.

3.4. Relationship of microplastics with grain size of sediment and seawater depth

The grain size distribution of the sediments from Banten Bay is presented in Table 1. The average percentage of the major fraction in the sediment was silt (53.25%), followed by clay (26.19%), sand (18.38%), pebbles (1.32%), and granules (0.86%) (Fig. S1, SI). Present results was coherence with previous study conducted in the Banten Bay that the predominant type of particle size of sediment were clays and silts in the size range of 3–55 μm (Hoitink and Hoekstra, 2005). Microplastics concentrations were significantly related to the clay and sand of sediment which a positive correlation with silt ($r = 0.71$, $p < 0.05$) and negative correlation with sand ($r = -0.7$, $p < 0.05$). However, when we correlated with seawater depth, there was no significant correlation with microplastics in sediment (Fig. 9). Previous study about suspended sediment concentration (SSC) and particle size variation in the Banten Bay found that the erosion and subsequent deposition was the main trigger on variation of suspended mass concentration (Hoitink and Hoekstra, 2005). Therefore, in our hypothesis, the distribution of microplastics in the sediment might be governed by similar factor that influence sedimentation in the Banten Bay such as sea current and tidal flow.

4. General discussion

Based on our results, there are several major points that need to be addressed, particularly related to the high abundance of EPS (Expanded Polystyrene) in Banten Bay, reaching up to 30.4%. These results are consistent with those found in other studies where marine aquaculture with a Styrofoam buoyancy aquaculture system is massively applied in the area (Eo et al., 2018). This finding also provided information related to the sinking processes of buoyant MPs to the seafloor and their potential impacts on pelagic and benthic organisms.

Commonly, EPS, with density lower (0.01–0.04 g/cm^3) than seawater (1.02–1.029 g/cm^3), will float on the surface (Ashida and

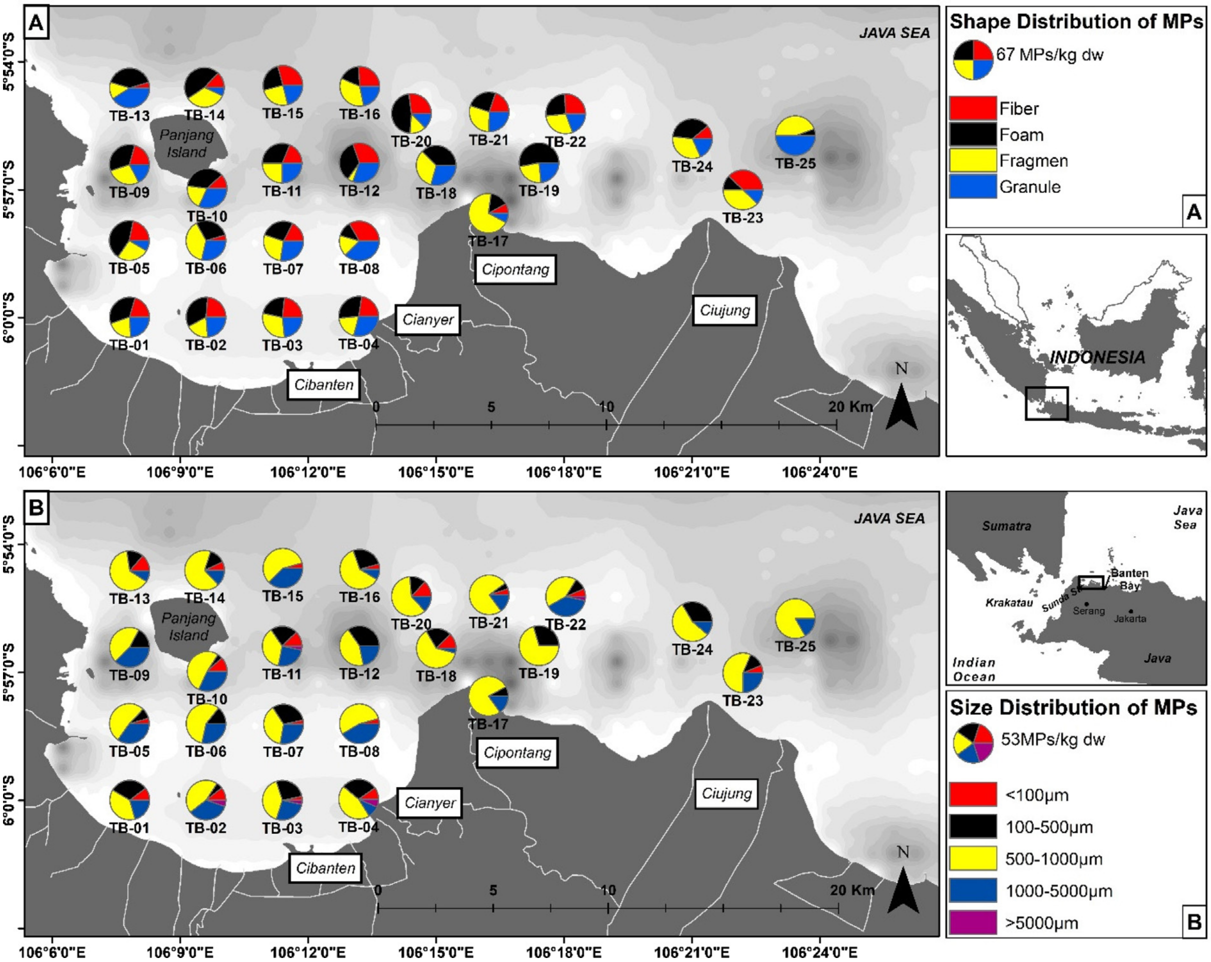

Fig. 4. Spatial distribution of microplastic shapes and size in the sediment from Banten Bay.

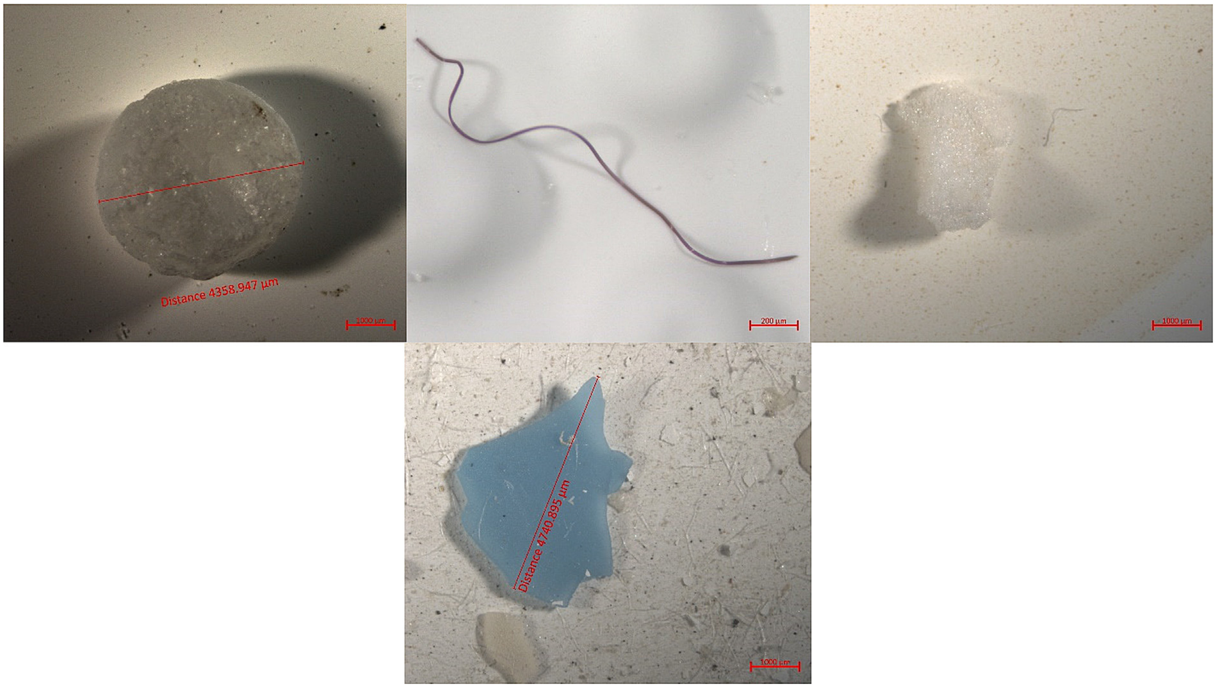

Fig. 5. Types of microplastics in the sediment from the Banten Bay: a. granules (n = 146), b. fibers (n = 112), c. foam (n = 182), and d. fragments (n = 159).

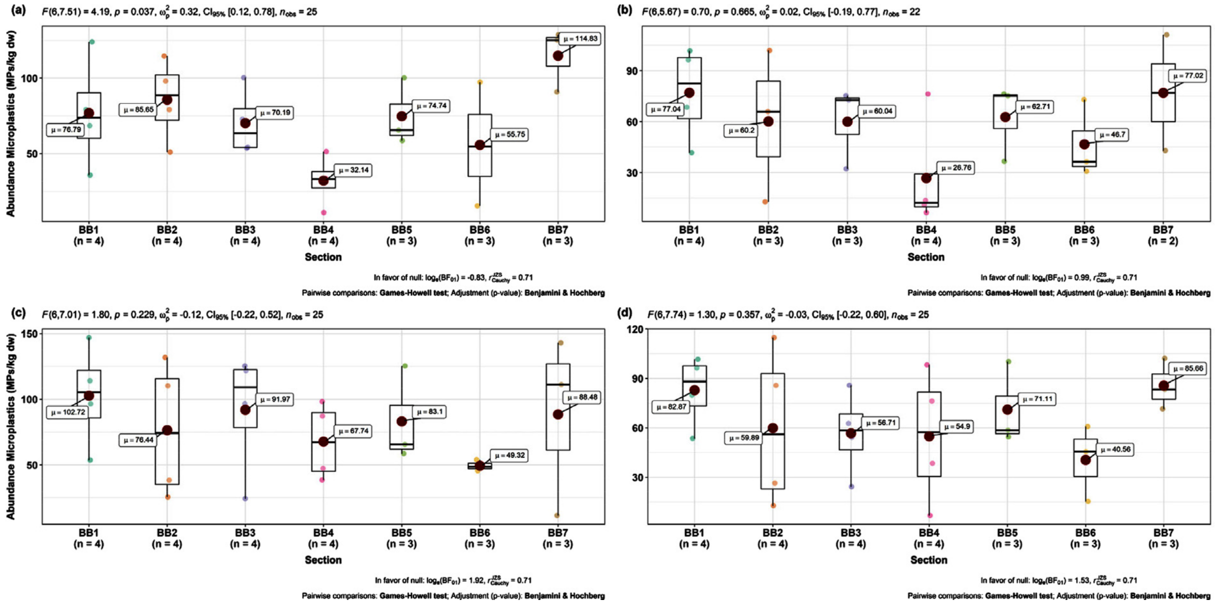

Fig. 6. Comparison of different types of microplastics between section site along the Banten Bay; significance was observed for (a) fragment; no significance was observed for (b) fiber, (c) foam, and (d) granule. Welch's ANOVA at 0.05 level of significance.

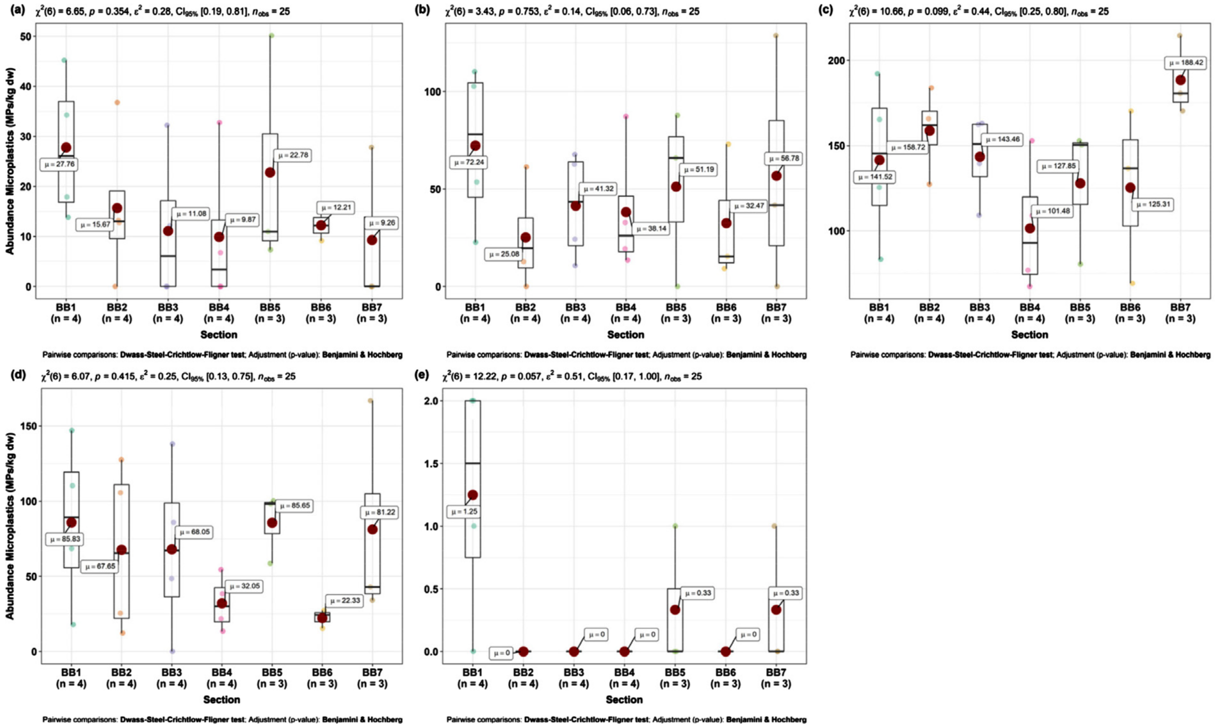

Fig. 7. Comparison of different sizes of microplastics between section along the Banten Bay; no significance was observed. Kruskal–Wallis non-parametric test.

Iwasaki, 1995). However, most of the foam's MPs surface observed during this analysis was mainly covered by the sediment layer. Based on these findings, the EPS density could be changed via aggregation processes in the water column between EPS MPs, sediment particles, and microorganisms. Moreover, a previous study reported that microorganisms are able to attach to MPs and create a biofilm surface (Rummel et al., 2017). Similar processes were also found in other experimental studies with phytoplankton aggregations.

Two different algae species were used (the diatom *Chaetoceros neogracile* and the cryptophyte *Rhodomonas salina*) (Long et al., 2015). These processes are defined as "fouling", where increasing numbers of MPs with densities reaching the density of water directly caused the MPs to sink and settle in the sediment (Fazey and Ryan, 2016). As a result of this kind of process, buoyant MPs in the ocean will be distributed both horizontally in the water surface and vertically through the water column. Therefore, these processes will allow the impacts of MPs to spread outside their source location and increase their bioavailability to be ingested by a large range of biota (Kooi et al., 2017). Moreover, this mechanism (aggregation and fouling processes) also provides information for further monitoring MPs in sediments. Areas with high percentages of total

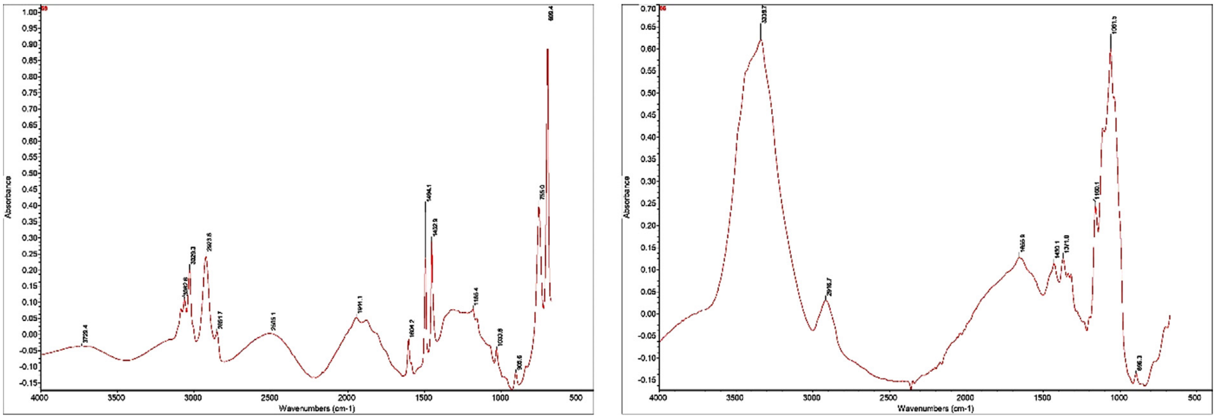

Fig. 8. FTIR spectra of selected microplastic particles, cellophane (left) and polystyrene (right) from sediment in the Banten Bay.

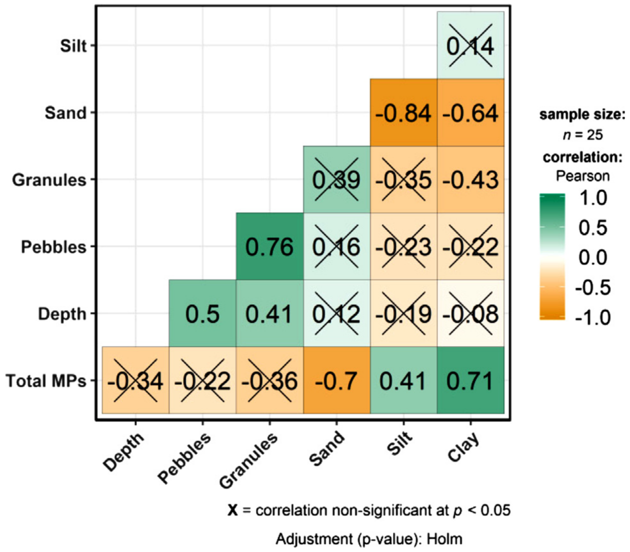

Fig. 9. Correlation graph between microplastics abundance with sediment characteristics and seawater depth. Positive correlation between total microplastics with silt and clay, and negative correlation with sand.

organic carbon (TOC) contents and the finest sediment grain sizes will be hotspots for MPs monitoring in marine environment (Maes et al., 2017). As mentioned in a previous study, sediment characteristics, including TOC content and grain size, have important roles in the distribution and accumulation of MPs on the seafloor (Vermaire et al., 2017). Though different interaction between MPs, TOC and sediment grain size have already been reported (Maes et al., 2017), in this study, we conducted a correlation analysis and found that the abundance of MPs was negatively correlated with sand and positively correlated with clay ($p < 0.01$). This condition indicates that the abundance of MPs increased with decreasing sediment particle size. Moreover, Eo et al. (2018) observed that fine grain size was associated with a high proportion of TOC and contaminants.

In addition, Rochman *et al.* (2013) stated that EPS MPs acted not only as a sink location but also as a source of polycyclic aromatic hydrocarbons (PAHs) in the environment. Thus, the impact of PS particles, including EPS, will potentially pose a greater risk to the environment than other types of MPs because of their dual-action. Therefore, the impact will be even more severe for benthic organisms because of the physical stressor of MPs in addition to chemical contaminants being transferred from water when moving through the water column and partitioning from the sediments to MPs (Crawford et al., 2017). Moreover, due to their size being similar to natural prey and their high concentration in the sediments, the MPs in sediments will have a high bioavailability and be ingested by benthic organisms in the sediment and could be toxicologically affected by the co-pollutants present in the MPs, such as persistent organic pollutants (POPs) (Andrady, 2011). As a consequence, the ingestion of MPs-associated contaminants in sediments increases the exposure of benthic organisms to hazardous chemicals and possibly the threat of bio magnification throughout the food web. Finally, further research is needed to validate the methodology used in the current study and to observe the temporal conditions of MPs pollution in coastal ecosystems in other locations in Indonesian waters.

5. Conclusions

The results of this study indicate that the MPs found in the sediments of Banten Bay are present at relatively low concentrations compared to the levels found other regions. Furthermore, the high abundance of EPS particles in the sediment confirmed the aggregation and biofouling mechanism in the water column that made the low-density MPs sink to the seafloor. A clear significant relationship between the MPs concentrations and the sediment grain size, but not with seawater depth. Finally, further research is needed to validate the methodology used in the current study, to observe interaction between different microplastic shape and size with grain size of sediments, and to observe the temporal conditions of MPs pollution in the shallow water of the Banten Bay.

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CRediT authorship contribution statement

Dede Falahudin: Investigation, Resources, Formal analysis, Writing - original draft. **Muhammad Reza Cordova:** Conceptualization, Resources, Investigation, Methodology, Writing - original draft. **Xiaoxia Sun:** Resources, Funding acquisition, Supervision, Writing - review & editing. **Deny Yogaswara:** Visualization, Data curation. **Ita Wulandari:** Visualization. **Dwi Hindarti:** Supervision, Funding acquisition, Writing - review & editing. **Zainal Arifin:** Supervision, Writing - review & editing.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.135304.

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