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Contamination of seabed sediments in Tokyo Bay by small microplastic particles

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ABSTRACT

This study investigated small microplastic particle (SMP, < 350 μm) contamination in the surface seabed sediment of the inner part of Tokyo Bay. The SMP concentration during the rainy season (May) was 100.3 ± 45.8 pieces g^{-1} dry weight and higher in the inner side of the bay, whereas that of the dry season (January) was 147.6 ± 19.5 pieces g^{-1} dry weight. There was no seasonal difference. The main plastic types found in the rainy season were polypropylene (PP), polyethylene (PE), and polyamide (PA). In the dry season (January), the concentration of PP decreased while that of PA increased. The mean SMP diameter did not change by site or season. Our results indicate that the seabed sediments in the inner part of Tokyo Bay are contaminated with relatively high concentrations of SMPs. Furthermore, the deposition rate of SMPs in the inner part of the bay was 12.4 mg cm^{-2} y^{-1}.

1. Introduction

In 2015, the annual production of plastics worldwide was an estimated 407 million tons (OECD, 2018), and the total production to date is approximately 8.3 billion tons (Geyer et al., 2017). Up until 2015, 6.3 billion tons of plastic waste was generated, and this amount is steadily increasing (Geyer et al., 2017). The amount of plastic waste entering the ocean has also increased, and it is estimated to be 1.15–2.41 million tons per year or 0.4–4.0 million tons per year from world rivers (Lebreton et al., 2017; Schmidt et al., 2017). An estimated 270,000 tons of plastic float on the surface of the world's oceans (Eriksen et al., 2014).

Plastics flowing out into the sea area deteriorate and break down into smaller fragments owing to the influence of ultraviolet rays and physical forces such as waves (Cole et al., 2011). Pieces of plastic with a major axis of 5 mm or less are called microplastics (MPs) (e.g., Andrady et al., 2011). They are widely distributed in waters around the world and have been confirmed in both polar regions (Lusher et al., 2015; Isobe et al., 2019). The quantity of MPs floating in subtropical ocean gyres was an estimated 10^6 pieces km^{-2} (Law and Thompson, 2014). The concentration of MPs is generally high in the waters around large cities (Kataoka et al., 2019). High MP concentrations have also been reported in East Asian waters (Isobe et al., 2015). Considering that the amount of plastic floating on the sea surface is very small relative to the amount flowing into the sea area, most plastics are likely submerged in the seabed or float in the seawater. It is thus highly possible that MP pollution has progressed in the seabed areas around large cities.

The MP concentrations in seabed sediments around large East Asian cities have been reported as 1.9 pieces g^{-1} dry weight (hereinafter pcs g^{-1} DW) in the Gulf of Thailand, 0.8 pcs g^{-1} DW in Changjiang Estuary, Shanghai, and 0.13 pcs g^{-1} DW in the Yellow Sea (Matsuguma et al., 2017; Peng et al., 2017; Zhang et al., 2019a,b). Because these past studies investigated MPs with a wide particle size range of 0.3 mm–5 mm, the concentration of smaller-sized MPs remains unknown. Tokyo Bay is a sea area surrounded by large cities. Matsuguma et al. (2017) found that the concentration of MPs measuring ≥350 μm in the canal bottom sediments in the inner part of Tokyo Bay was relatively high.

Therefore, it is important to quantify the concentrations of small MPs (<350 μm; hereafter SMPs) in the sea areas around metropolitan areas to elucidate the behavior of MPs along the coast and also to understand their effects on local organisms. In this study, we clarify the concentration distribution, seasonal changes, and properties of SMPs in the inner part of Tokyo Bay.

2. Materials and methods

2.1. Sample collection

In May 2019 and January 2020, the SMP concentrations in the

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sediments of the inner part of Tokyo Bay were investigated using the training ships *Seiyo-maru* (170 tons) and *Hiyodori* (19 tons) from the Tokyo University of Marine Science and Technology. Three sampling points were selected in the inner part of Tokyo Bay (Sta. 1: 35° 30′ 31.7″ N, 139° 49′ 48.3″ E, 26 m water depth; Sta. 2: 35° 29′ 11.8″ N, 139° 54′ 48.3″ E, 21 m water depth; and Sta. 3: 35° 25′ 11.8″ N, 139° 47′ 48.3″ E, 27 m water depth) (Fig. 1, Table 1). Sta. 1 was in the mouth of Tamagawa River Estuary, which is the potential microplastics source in Tokyo Bay (Kataoka et al., 2019). Sta. 2 was set on an extension of both the Tamagawa River Estuary and Sta. 1. Finally, Sta. 3 was set in the central part of Tokyo Bay.

Observations were conducted in May, and only Sta. 1 was observed in January. Samples could not be collected from Sta. 2 and 3 in January owing to inclement weather. In Tokyo, the early rainy season occurs in May and the dry season in January. A survey was executed in January to clarify the seasonal change.

Sediment collection was performed once at each station using an Ekman–Barge sampler (Rigo Co. Ltd., Tokyo, Japan). The collected sediment was transferred from the sampler to a metal container. The thickness of all the sediment samples was approximately 3–5 cm. The deposits were uniformly agitated and collected in washed PVC bottles with a capacity of 300 mL. The samples were taken back to the laboratory and stored in a cool, dark place.

2.2. Treatment of samples

For all samples, water content and sediment particle size, as well as size, polymer type, and concentration of SMPs, were analyzed. The water content was determined according to the water content in soil test method (Ministry of Economy, Trade and Industry of Japan, 2009) of the Japanese Industrial Standards. The water contents of the samples from Sta. 1, 2, and 3 were 79.37%, 77.98%, and 47.44%, respectively. The particle size distribution of each sample sediment was measured using a laser diffraction-type particle size distribution measuring device, SALD-2300 (Shimazu Co., Ltd., Tokyo, Japan). The average particle size and water content of the sediments are shown in Table 1.

The SMP concentration was measured with reference to Masura et al. (2015). Approximately 10 g (wet weight) of the sample was separated into a beaker. Next, 200 mL of NaI solution adjusted to a density of 1.6 g cm^{-3} was poured into the beaker, stirred, and left to stand for 60 min; the supernatant was then collected. At this time, about 80% or more of the supernatant of the NaI solution was recovered. The NaI solution was added to the remaining sample again and stirred. This density separation operation (density separation) was performed in triplicate.

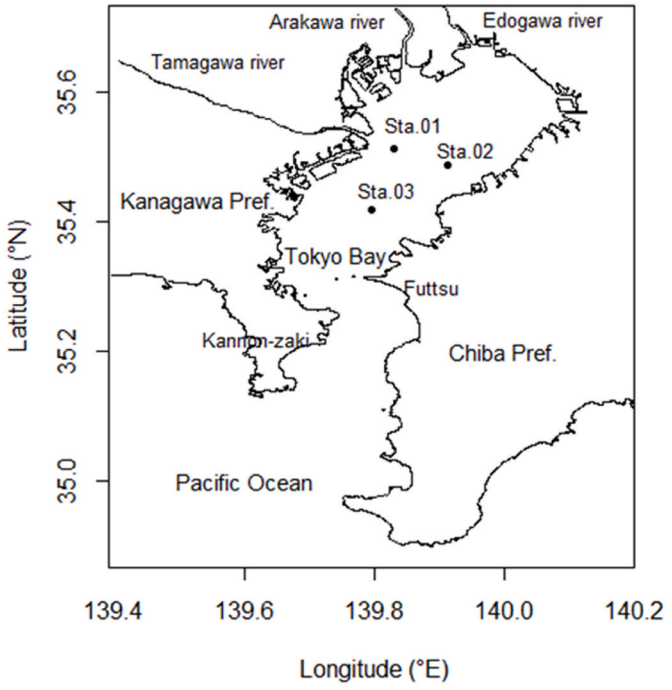

Fig. 1. Research area and sample collection stations.

After that, the collected supernatant was passed through a sieve with a mesh size of 15 μm, and the particles in the supernatant were collected. The particles remaining on the sieve were washed with distilled water. Afterward, 20 mL of 30% hydrogen peroxide was added to these particles and heated (72 h at 60 °C; e.g., Zhang et al., 2019a,b). Next, the particles were collected on a polytetrafluoroethylene (PTFE) filter (25 mm diameter, 1 μm pore diameter) by filtration. The PTFE filter was dried in a desiccator (room temperature) for approximately 12 h. The operation was repeated by separating three subsamples from the main sample at each station and using them as replicates.

2.3. Analysis of SMPs

The infrared absorption spectrum of the particles collected on the PTFE filter was measured using Fourier Transform Infrared Spectroscopy (FTIR) (IRT-7200, JASCO Co. Ltd., Tokyo, Japan) equipped with a linear-array infrared microscope. The magnification of the microscope was 16 times. The size of one pixel measured was 12.5 μm. The wavenumber range of the measurement was 4000–400 cm^{-1}. The number used for the ensemble average to obtain one spectrum was six times for sample measurement and 64 times for background (Phuong et al., 2018). The measured area was one-quarter the entire area of the circular filter. The image area for one measurement was 4 mm × 4 mm (320 pixels × 320 pixels). Following measurement, a moving average of 11 points was applied to the wavenumber spectrum of all pixels in the area, and the first derivative value of the spectrum was estimated.

The particles collected by the PTFE filter included not only SMPs but also other particles with a low specific gravity. In this study, six typical types of SMPs contained in sediments were detected as candidate particles: polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) (Geyer et al., 2017; GESAMP, 2019; Matsuguma et al., 2017). The correlation coefficients between the spectra of all candidate particles on the filter and the spectra of six standard plastics were calculated in a specific wavenumber range (Table S1). Contour images of the correlation coefficient of each measurement area were created for each polymer type.

If a particle had a correlation coefficient exceeding a threshold, which was calculated as the summation of mean values and three times the standard deviation of the correlation coefficients, it was considered an SMP candidate. Furthermore, the spectra of the SMP candidate particles were confirmed as belonging to a specific polymer type using the commercial library KnowItAll (Bio-Rad Laboratories Inc., CA, USA). At this time, the type of plastic was determined when the Hit Quality Index of the spectrum was 60% or more (e.g., Hanke et al., 2013; Zhu et al., 2019).

To measure particle size, the contour images of the correlation coefficients were binarized by the threshold of each polymer type. The major axis of the MP particles was then determined by the elliptical fit function in the image processing software ImageJ. Considering the 12.5 μm pixel size of the FTIR microscope and the 15 μm mesh size of the sieve, the 625 $μm^2$ (25 μm × 25 μm) size of the particle area was determined to be the minimum detection area of SMPs in this study.

2.4. Blank and recovery test

To examine whether there was any contamination of samples by plastic particles from the experimental environment, a blank test was conducted. A PTFE filter (47 mm diameter, 1 μm pore diameter) in a Petri dish was placed in the experimental room. After sample processing

Table 1
Collection point and characteristics.

Station	Month	Latitude (°E)	Longitude (°N)	Depth (m)	Mean diameter of sediment ± S.D. (μm)	Water content (%)
Sta. 1	May	139°49′48.3″	35°30′31.7″	26	21.4 ± 0.2	79.4
Sta. 2	May	139°54′48.3″	35°29′11.8″	21	30.4 ± 1.3	78.0
Sta. 3	May	139°47′48.3″	35°25′11.8″	27	114.6 ± 5.7	47.4
Sta. 1	Jan.	139°49′48.3″	35°30′31.7″	26	26.7 ± 1.4	76.5

was complete, the mixture of plastics on the filter was examined using the same method employed for the sample measurements. Because no mixed plastic was found, the possibility of contamination resulting from experimental procedures was dismissed.

The recovery percentage of SMPs from sediments depends on the methods or proficiency of the sample treatment. Recovery tests were performed to evaluate the actual SMP concentration in the sediment. Twenty spherical standard polyethylene particles (Codpheric CPMS-0.96, Corefront Co. Ltd., Tokyo, Japan) of various sizes (45 μm, 90 μm, 180 μm, and 300 μm) were mixed into the Sta. 1 sediments. The polyethylene particles were recovered by density separation and oxidation treatment with hydrogen peroxide, as for the sediment samples of this study. The recovered particles were observed with an optical microscope (100 × magnification), the polyethylene particles were detected by their spherical shape, and the number recovered was recorded. The recovery percentage was calculated using equation (1):

$$R = \frac{C_r}{C_i} \times 100, \quad (1)$$

where R is the recovery percentage (%) and C_r and C_i are the respective numbers of polyethylene particles recovered from the sample sediment and mixed in with the sediment.

2.5. Statistical analysis

The SMP concentration and diameter difference were compared for three sites during the rainy season. However, the differences between the rainy and dry season were only assessed for Sta. 1. The Kruskal–Wallis multiple comparison test was used to compare the SMP concentration and particle size at each observation point. The calculation was performed using R statistical software (R Development Core Team, 2016). Additionally, a cluster analysis was performed using Ward's method to compare the similarity of polymer types in each sea area (SPSS Statistics, IBM, USA).

3. Results

3.1. Spatial and temporal distribution of SMPs

Large-sized, visible MPs were not found in any sediment samples from the inner part of Tokyo Bay. The SMP concentrations of the seabed sediments at Sta. 1, 2, and 3 during the rainy season (May 2019) were 145 ± 21.5, 103 ± 28.6, and 53.3 ± 4.1 pcs g^{-1} DW, respectively (Table 2). The SMP concentration at Sta. 1 in May 2019 was significantly higher than that of Sta. 3 (Kruskal–Wallis test, $p < 0.05$). The polymer type found at each station is summarized in Fig. 2. At Sta. 1 in May (Fig. 2a), PP was the main polymer type, whereas PA was high at Sta. 3.

Table 2
Concentrations of small microplastic particles.

Station	Month	N	Concentration ± S.D. (pcs g^{-1} DW)
Sta. 1	May	3	145 ± 21.5[b]
Sta. 2	May	3	103 ± 28.6[a,b]
Sta. 3	May	3	53.3 ± 4.1[a]
Sta. 1	Jan.	3	148 ± 19.5[b]

Characters a and b indicate significant differences at $p < 0.05$.

In May, Sta. 1 had small quantities of PS and PVC. In the preliminary sample analysis, one PET particle was observed from the Sta. 1 sample from May.

No microbeads or resin pellets were found at any of the stations. The size ranges (average particle size ± standard deviation) of the SMPs were 45.4–298.5 μm (75.5 ± 45.3 μm) at Sta. 1 in May, 33.0–204.2 μm (71.9 ± 36.1 μm) at Sta. 2, and 30.4–480.7 μm (75.5 ± 47.9 μm) at Sta. 3. There were no significant differences among stations in terms of the average SMP particle size (Kruskal–Wallis test, $p > 0.05$).

At Sta. 1, the SMP concentration during the dry season (January 2020) was 148 ± 19.5 pcs g^{-1} DW (Table 2), which did not differ significantly from that of May 2019 ($p > 0.05$). The types of plastics found in January were PP (22%), PE (11%), PA (24%), PS (3%), copolymer (18%), and other synthetics (22%) (Fig. 2d).

The minimum, maximum, and average particle sizes at Sta. 1 in January were 32.1 μm, 234.1 μm, and 68.3 ± 36.7 μm, respectively. No significant difference was found between January and May at Sta. 1 in terms of average particle size ($p > 0.05$). The average particle sizes of PP and PE were 73.3 ± 33.7 μm and 70.1 ± 28.9 μm, respectively, and no significant differences were observed ($p > 0.05$).

3.2. Recovery percentage of SMPs

The recovery percentages for the plastic particles measuring 45 μm, 90 μm, 180 μm, and 300 μm were 72.6 ± 12.5%, 84.6 ± 11.3%, 94.4 ± 7.9%, and 100 ± 0%, respectively (Table 3). Smaller particle sizes had a lower recovery percentage.

4. Discussion

4.1. SMP contamination of seabed sediments in the inner part of Tokyo Bay

The SMP concentration in the sediment of Tokyo Bay tended to be higher toward the inner part of the bay. Matsuguma et al. (2017) found that the concentration of MPs measuring 335 μm to 5 mm was 1.8 pcs g^{-1} DW in the sedimentary particles in the canal (35° 35′ 46.2″ N, 139° 44′ 51.5″ E) in the innermost part of Tokyo Bay. Meanwhile, in this survey, the concentration of MPs measuring 335 μm or larger was 0.8 pcs g^{-1} DW at Sta. 3, and none were found at Sta. 1 or Sta. 2. The concentration was lower than that of the canal (Matsuguma et al., 2017), which is likely because the observation station used here was located off the canal. In this study, the concentration of SMPs in the size range of 25–335 μm was 145 pcs g^{-1} DW at Sta. 1 in May. That is, if the particle size distribution of plastic particles in the canal was the same as in Sta. 1, there were likely more SMPs in the canal than at Sta. 1.

Kataoka et al. (2019) examined river water in Japan and showed that both urbanization rate and biological oxygen demand are positively correlated with MP concentration. Tokyo Bay has a basin population of 31 million (Tokyo Bay Environmental Information Center, 2003), and it is an area with a high urbanization rate. The reported SMP concentrations in the sediments of other urban areas are 0.8 pcs g^{-1} DW in the Changjiang Estuary in China (Peng et al., 2017) and 1,000–30,000 pcs g^{-1} DW in the Santos and São Vicente Estuary in Brazil (Gimiliani et al., 2020). The SMP concentration of the sediment in the inner part of Tokyo Bay was between those of the two sea areas. All these sea areas also have a large basin population, but there are overcrowded and impoverished

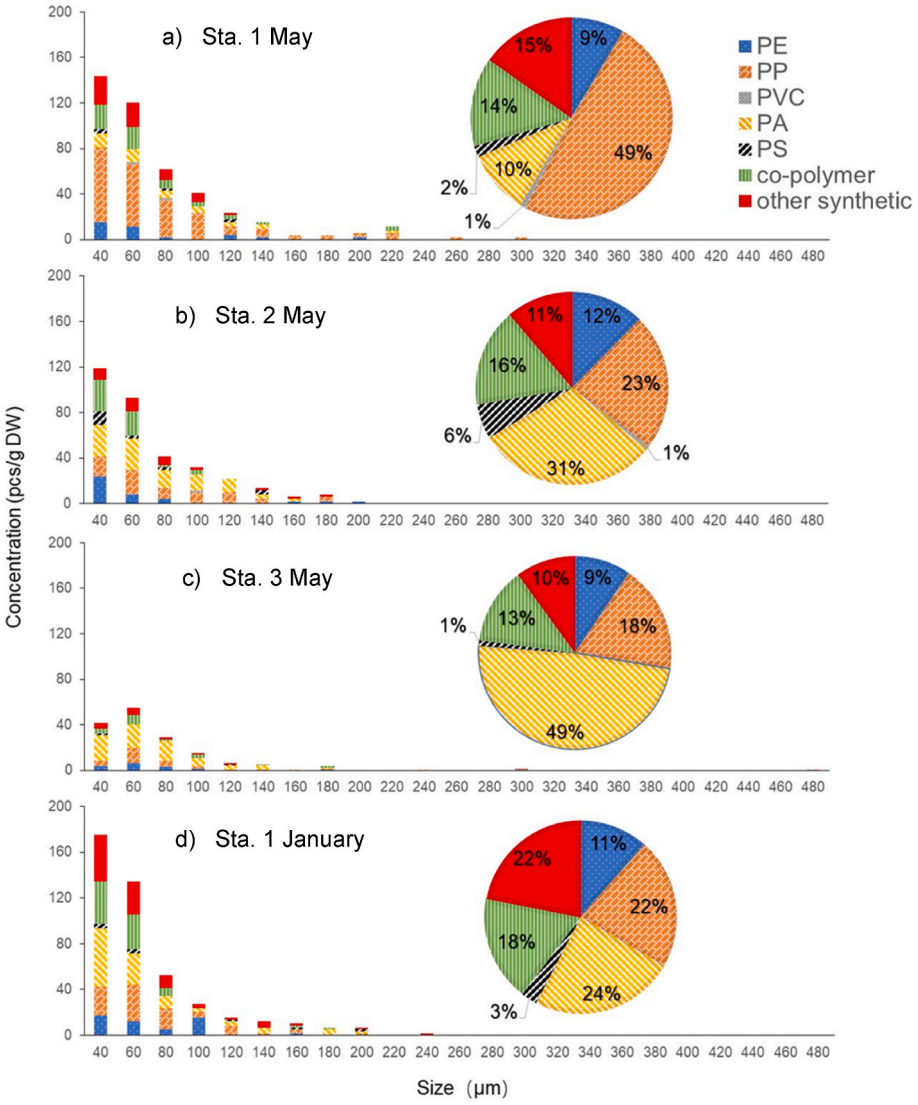

Fig. 2. Components and particle diameters of small microplastic particles
PE; polyethylene, PP; polypropylene, PVC; polyvinyl chloride, PA; polyamide, PS; polystyrene.

Table 3
Recovery percentages of small microplastic particles.

Diameter of standard plastics (μm)	n	45	90	180	300
Recovery percentage ± S.D. (%)	3	72.6 ± 12.5	84.6 ± 11.3	94.4 ± 7.9	100 ± 0

areas around the Santos Estuary. The status of SMP contamination on the seabed was somewhat related to the coastal population and the ability to manage plastic waste.

We set Sta. 1 and Sta. 2 on the extension of the estuary of the Tamagawa River in Tokyo Bay. Sta. 3 was set in the center of Tokyo Bay. The residual current in Tokyo Bay runs clockwise (Suzuki et al., 2012). However, the current in the inner part of the bay is complicated owing to the large inflow of river water and the influence of wind (Hattori, 1983). The deposition of particles containing SMPs in Sta. 1 and 2 is likely strongly affected by the flash out that often occurs during heavy rains on Tamagawa River.

The average sizes of the sediment particles at Sta. 1 in May (rainy season) and in January (dry season), Sta. 2, and Sta. 3 in Tokyo Bay were 21.4 ± 0.2, 26.7 ± 1.4, 30.4 ± 1.3, and 114.6 ± 5.7 μm, respectively (Table 1). The average particle is smaller toward the inner part of Tokyo Bay. The average flow velocity is slower toward the inner part, especially, in the slower bottom layer (Hattori, 1983). Because the sedimentation speed of fine particles is relatively slow, a slow flow velocity is a likely condition for the deposition of the finer size particles.

Additionally, a significant correlation was found between SMP concentration and sediment particle size (n = 12, $rs = -0.76$, Spearman's rank correlation coefficient test, $p < 0.01$); the smaller the sediment particle size was, the higher the SMP concentration tended to be. This has also been confirmed in other waters (Liebezeit et al., 2012; Vianello et al., 2013; Molinaroli et al., 2007).

Matsuguma et al. (2017) found that in the Tokyo Bay Canal, the major MP types and their composition ratios were PE (26.3%), PP (5.3%), PS (5.3%), PET (10.5%), and PA (15.8%). Similarly, in this study, PE, PP, and PA were the main SMP types in the inner part of Tokyo Bay. The only difference between our results and those from the canal is that high-density SMPs such as PVC were briefly observed only at Sta. 1, which is the closest station to the Tamagawa River mouth. The shapes of microplastics are classified as fragments, foam, film, and lines (GESAMP, 2019). In our microscopic observations, all of the SMPs examined appeared to be "fragments." The specific densities of plastics range from 0.85 to 0.86 for PE and PP, approximately 1.0–1.1 for PS and

PA, and around 1.33 to 1.39 for PET and PVC (Polymer Properties Database, accessed July 22, 2021). Because the SMPs of PE, PP, and PA fragments have almost the same sedimentation rates, they would likely behave similarly and be widely distributed in the sea upon release from the estuary. Therefore, high-density SMPs such as those made of PVC and PET flow out of the canal through rivers and drainage facilities. However, the high-density SMPs likely settled and accumulated near the coast and did thus not flow out to the central part of the bay, even when the river flow was strong.

Furthermore, low-density SMPs aggregate rapidly when biofilms are formed in the environment (e.g., Michels et al., 2018). The aggregated particles likely settle immediately. The low-density SMPs that have settled near the seafloor react to even a slight flow in the bottom layer. Thus, SMPs are likely to accumulate when the flow is weak. However, the SMP deposition mechanism is complicated owing to resuspension caused by the flow of the bottom layer near the seabed. The concentrations of other particles that are not MPs increase near the seabed of Tokyo Bay (Matsuike et al., 1986), in which case, these particles may adsorb to the MPs. Once the particles are deposited, their movements may be further complicated because the MPs no longer exist on their own.

Furthermore, a cluster analysis was performed on the composition ratio of plastics (MPs and SMPs) obtained around Tokyo Bay (Fig. S1). In this analysis, composition ratios (PE, PP, PA, PS, and other synthetics) of Tokyo Bay sea surface MP (Nakano et al., 2021), Tokyo Bay Canal sediment MP (Matsuguma et al., 2017), and sediment SMP (present study) types were used. The composition ratio of MPs and SMPs collected in Tokyo Bay can be classified into two groups: 1) sea-surface water MPs and canal sediment MPs, and 2) bay sediment SMPs (this study). The cluster of SMPs in the sediments at the inner part of the bay differed from the cluster of MPs in the sea surface and estuary sediments. In other words, the SMPs on the seabed at the inner part of Tokyo Bay are not caused by the MPs on the sea surface at the inner part of the bay or those deposited on the canal that have become smaller as a result of deterioration. It is likely that SMPs of different origins are deposited on the seabed in the inner part of Tokyo Bay. Further data collection is required to elucidate the behavior of MPs and SMPs in Tokyo Bay.

4.2. Deposition rate of SMPs

According to the recovery test, all MPs could be reliably recovered when the particle size was 300 μm or greater. When the recovery percentage was 180 μm or less, the particle size was smaller and the recovery percentage was lower (Table 3). When the particle size was 45 μm, the recovery percentage was about 73%. According to Phuong et al. (2018), the plateau was about 80% in ten recovery experiments. In this experiment, approximately 80% of the plastic particles of 40–90 μm in diameter could be recovered by the recovery operation using three density separations. It is considered that the small plastic particles in the seabed sediment were mostly recovered by the method of this study.

The seabed sediment particle size likely affects the recovery percentage of SMPs. Because SMPs and sediment particles adhere to each other, SMP recovery becomes more difficult with smaller sediment particles. In this study, Sta. 1 particles with the finest particle size were used for the recovery test, so the recovery percentage at Sta. 3 may actually be higher. This is because the relatively larger particles in the Sta. 3 sample can reduce the trapping and aggregation of SMPs in the sediment.

Based on the results of the recovery test, the SMP concentration at Sta. 1 was underestimated at a particle size of approximately 45 μm. Therefore, the actual SMP concentration for particle sizes of 180 μm or less was estimated by multiplying the observed concentration by the recovery percentage (Table S2). The particle sizes used for the estimations were 45 μm for particles measuring 30–70 μm, 90 μm for particles measuring 70–140 μm, 180 μm for particles measuring 140–240 μm, and 300 μm for particles measuring 240–360 μm. As a result, the SMP concentration after correction of Sta. 1 was 560 pcs g^{-1} DW (Table S2).

Because the SMPs were mainly composed of PP, PE, and PS, the density was approximately 1.0 g cm^{-3}. Assuming that all the particles were spherical, the volume of SMPs at Sta. 1 was 1.28×10^{-4} cm^3. From this, the weight concentration of SMPs was 20.7 mg g^{-1} DW. The deposition rate of sediment particles off the Tamagawa River in Tokyo Bay (near Sta. 1) was reported as 0.6 g cm^{-2} y^{-1} (thickness; 0.89 cm y^{-1}) (Okada et al., 2016). In this survey, the bottom surface sediments were collected to a depth of about 3–5 cm and analyzed uniformly. This survey thus measured the average of particles over the past 4–5 years. The SMP deposition rate in recent years was an estimated 12.4 mg cm^{-2} y^{-1} (1.24 kg km^{-2} y^{-1}).

In this study, fine microplastics occurred at a relatively high concentration in seabed sedimentary particles from the inner part of Tokyo Bay. In the future, it will be necessary to study the effects of SMP uptake on benthic organisms in Tokyo Bay.

5. Conclusions

In this study, we clarified the SMP concentration, distribution, and seasonal changes in the sediment in the inner part of Tokyo Bay. The SMP concentration of 145 pcs g^{-1} DW on the inner side of the bay was higher than the 53.3 pcs g^{-1} DW on the mouth side of the bay. No seasonal changes in SMP concentration were observed. SMP sizes ranged from 30 μm to 480 μm, with smaller SMPs being more numerous. There was no difference in the average particle size of SMPs at the observation points. PP, PE, and PA accounted for more than 60% of the SMP types. When the deposition rate of SMPs was estimated from the deposition rate of sediment particles in the inner part of Tokyo Bay, it was found to be 12.4 mg cm^{-2} y^{-1}. That is, 1.24 kg km^{-2} y^{-1} of SMPs has been deposited on the seabed in the inner part of Tokyo Bay in recent years.

CRediT authorship contribution statement

Yehao Wang: Formal analysis, Investigation, Writing – original draft. **Haruka Nakano:** Formal analysis, Investigation, Writing – review & editing. **Haodong Xu:** Formal analysis, Investigation. **Hisayuki Arakawa:** Writing – review & editing, Writing – original draft, Project administration.

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.ecss.2021.107552.

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