

Microplastic abundance and its relationship with sediment grain size in seagrass and bare flats of Panjang Island, Banten Bay, Indonesia

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Abstract. Microplastic accumulation in sediment is influenced by the grain size of sediment. Panjang Island, located in Banten Bay, has the potential to accumulate microplastics from bay-wide transport and local anthropogenic sources. This study assessed the relationship between sediment grain size and microplastics in seagrass and bare flat sediments. Sediment samples were collected from seagrass, seagrass edges, and non-seagrass areas at three stations ($n = 9$). Differences among sampling points were evaluated using Kruskal–Wallis, while relationship between microplastic and sediment grain size was assessed using Spearman’s coefficient and principal component analysis (PCA). Microplastic abundance ranged from 240 to 1.880 par kg^{-1} dw with no significant differences among sampling points ($p > 0.05$). Microplastics were dominated by fragments and fibers, with fine and medium sand being the dominant sediment grains. A positive correlation was observed between microplastic abundance and finer sediments ($r_s = 0,58$), suggesting that microplastic increases with the proportion of fine sand. PCA results showed an association between microplastic abundance and sampling points located in seagrass beds, suggesting that seagrass may enhance microplastic accumulation in the sediments of Panjang Island.

Keywords: Grain size, microplastics, Panjang Island, sediment

1 Introduction

Microplastics are solid synthetic particles measuring <5 mm that can be produced in micro sizes (primary microplastics) or as a result of the fragmentation of larger plastic items (secondary microplastics) [1]. After entering the ocean, waves and sunlight can cause degradation of larger plastics through mechanical and photochemical processes [2]. The relatively lower density of some microplastics polymer, such as polypropylene (0.85 – 0.92 g/mL) and polystyrene (0.01 – 1.06 g/mL) compared to seawater (1.025 g/mL) [3] causes microplastics to float, although microplastics can also move vertically and eventually be

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deposited in the sediment [4]. In coastal areas, vegetation, such as seagrass, can trap marine debris, including microplastics, leading to the accumulation of particles in seagrass beds [5].

In sediment, the composition of the sediment grain size plays a role in the distribution of microplastics [1]. Previous research has reported that finer sediments contain more microplastics [6, 7] and are more efficient at trapping them [8]. A higher composition of finer grains indicates a low hydrodynamic energy area, and vice versa. In other words, a low-energy environment increases the potential for sediment deposition, along with other particles, such as microplastics [6]. A dynamic environment often causes fine particles to be transported and suspended, making particle deposition even more difficult [9].

The presence of seagrass vegetation can alter and reduce the current velocity and wave energy owing to canopies formed by seagrass [10, 11]. After entering the seagrass ecosystem, microplastic particles can become trapped by attaching themselves to seagrass leaves or accumulating at the bottom of water; [5] thus, significant differences in microplastic abundance can be found between seagrass sediments and bare sediments [12]. Previous studies have shown the role of seagrass in trapping microplastics [12–14], indicating that seagrass may act as a sink and is effective in preventing the distribution of microplastics in wider areas [13].

Seagrass vegetation in Indonesia can be found on Panjang Island, which is located in Banten Bay. Panjang Island might have received microplastic pollutants from Banten Bay [15], Sunda Strait [16], and the activities of the local residents of Panjang Island [17]. The microplastics in Banten Bay have been studied previously [4,15,18], although none have been studied specifically in the seagrass area of Panjang Island. Accumulated microplastics in seagrass areas can be ingested by grazers [12,19] and other biota living in the ecosystem. Therefore, this study aimed to: 1) analyze the microplastics and sediment fractions from seagrass and bare sediment, and 2) analyze the relationship between microplastics and sediment grain size.

2 Method

2.1 Sampling location

Sediment samples were collected at three stations, KD, P1, and P2, located in the northern and southwestern parts of Panjang Island (**Fig. 1**). During low tide, a 15 m transect line was laid perpendicular to the shoreline and divided into three points: seagrass area, seagrass boundary, and non-seagrass area (modified from [5]). These three points were used to distinguish the environmental conditions based on the presence of seagrass. Samples were collected using a stainless-steel shovel and placed in aluminum bags. Nine samples were collected and three samples were obtained from each station. The samples were stored in a freezer at ≤ 0 °C.

2.2 Fractionation of sediment

Sediment grain size was measured using the dry sieve method [20]. The sediment was dried in an oven (60 ± 1 °C) for 24 h or until it dried. The aggregated sediment was then separated and homogenized using a mortar and pestle. The homogenized sediment sample (50 g) was sieved using stainless-steel sieves with mesh sizes of 2, 1, 0.5, 0.25, 0.125, and 0.063 mm. Each sample retained in each sieve was weighed according to the sediment grain size. Sediments were classified according to the Wentworth scale [21] as gravel, coarse sand, medium sand, fine sand, very fine sand, and mud (clay/silt).

2.3 Extraction and identification of microplastics

Nine sediment samples from each sampling point were oven-dried overnight at 60 °C [22]. A total of 50 g of sediment was mixed with 100 mL of saturated NaCl solution and left overnight to separate microplastics from the sediment [23]. NaCl solutions have been used in previous studies to separate microplastics from sediment particles [4,13,24]. The NaCl solution is also considered to be less expensive and easier to prepare [13]. The resulting supernatant was then biogenically digested using 20 mL of 30% H₂O₂ solution. The mixture was filtered using 0.45 µm Whatman filter paper and stored in a petri dish at room temperature for identification.

All particles on the filter paper were examined under an Olympus SZ61 microscope connected to a camera and BetaView software. In this study, the polymer composition of the particles was not assessed; instead, they were categorized based solely on their physical characteristics as a rapid and economical method to assess their distribution [5]. According to [25], microplastics are characterized by 1) homogeneous color and lack of luster, 2) absence of organic structures and living cells, and 3) lack of branching for fiber-type microplastics. Microplastics were categorized based on their shape and size. The shape of microplastics was classified into fibers, fragments, foam, and granules [26], while the size was classified into 0.1–0.3 mm, 0.3–0.5 mm, 0.5–1 mm, and 1–5 mm [27]. The abundance of microplastic was reported as per kg kg⁻¹ dw (particle kg⁻¹ dry weight of sediment).

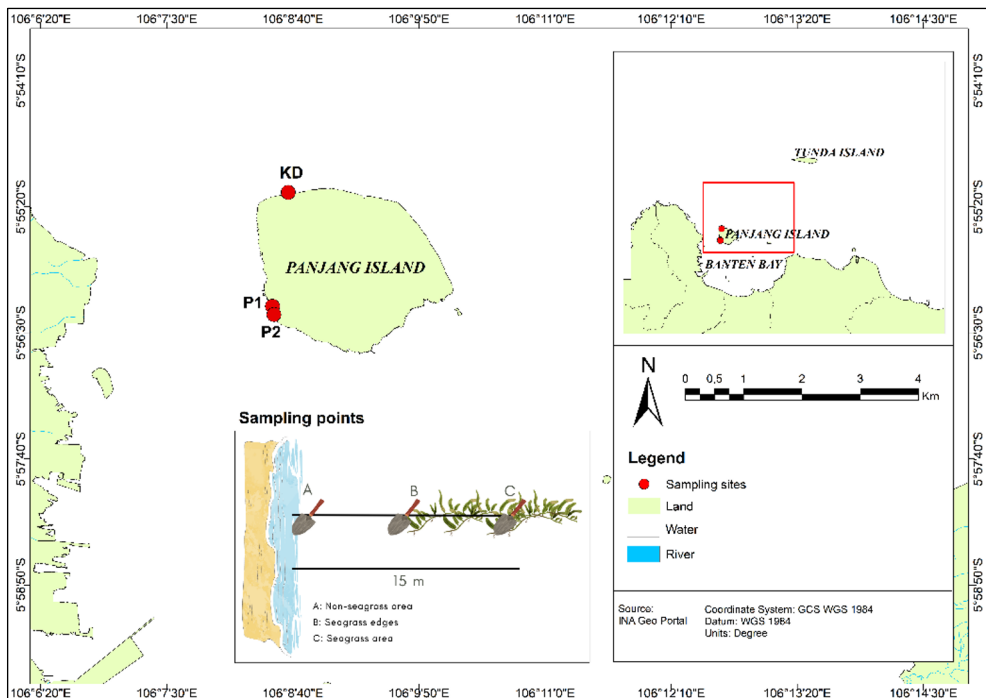


Fig. 1. Sampling stations map and points in Panjang Island, Banten.

2.4 Contamination prevention

This procedure was used to prevent contamination of the samples. After processing, the samples were covered with an aluminum foil. The use of plastic-based equipment was minimized, and all equipment (e.g., petri dishes and measuring glasses) used from sample collection to microplastic extraction were washed with distilled water. All solutions were

filtered through 0.45 μm Whatman filter paper before use and immediately stored in glassware covered with aluminum foil. Cotton-based clothing was also worn during sample processing to further reduce the contamination risk.

2.5 Statistical analysis

Significant differences in microplastic abundance in the sediments were identified using the Kruskal-Wallis test. A $p > 0.05$ indicates no significant difference, while a $p < 0.05$ is the opposite. The relationship between sediment grain size and total microplastic abundance was determined using Spearman's correlation analysis [28]. Spearman's coefficient (r_s) was categorized into five classes [29]: 1) Negligible: 0 ± 0.20 ; 2) Weak correlation: 0.21 ± 0.40 ; 3) Moderate correlation: 0.41 ± 0.60 ; 4) Strong correlation: 0.61 ± 0.80 ; 5) Very strong correlation: 0.81 ± 1.00 . Both analyses were performed in PAST (PAleontological STATistics) v4.03 software. Finally, Principal Component Analysis (PCA) was performed in Rstudio to examine the association between microplastics, sediment grain size, and sampling location. Eigenvalues exceeding 1.1 were retained in this study, as they were deemed to sufficiently account for the data variance.

3 Results and discussion

3.1 Total abundance of microplastic

Microplastics were found in all sediment samples, with abundances ranging from 240 to 1,880 $\text{par kg}^{-1} \text{ dw}$ (Fig. 2a). The average abundance was $657.78 \pm 516.64 \text{ par kg}^{-1} \text{ dw}$ and the median was 420 $\text{par kg}^{-1} \text{ dw}$ (IQR = 340-860 $\text{par kg}^{-1} \text{ dw}$). The highest abundance of microplastics was found in the seagrass sediment (P1-SG), and the lowest abundance of microplastics was found in the seagrass vegetation boundary sediment (KD-SGB). The abundance of microplastics in this study was relatively lower than that in Ancol and Pluit [30] but higher than that in the Surabaya coast, [31] although both are located close to residential areas as sources of plastic. Microplastics in the seagrass beds of Pramuka Island, [32] which is a tourist area located in the Seribu Islands, were also found to be lower than those in this study. A comparison of the total abundance of microplastics in the sediments of Indonesia is presented in Table 1.

Stranded macroplastic waste along the coast of Panjang Island is likely to contribute to the high abundance of microplastics through fragmentation processes. However, local sources such as tourism, fishing, and solid waste disposal activities are also considered potential contributors [13]. It is suggested that the relatively high level of anthropogenic activity around station P1 contributes to the high microplastic input in the surrounding waters compared with other stations. The southwestern area of Panjang Island is often used for fishery capture [33]. This area is also close to the residential area of Pulau Panjang and is a ship port [34] that is quite dense with anthropogenic activity, implying the possibility of high plastic input to the surrounding water.

Seagrass may play a role in trapping microplastics in sediments [12, 14]. This is related to the canopy formed by seagrass leaves, which allows microplastics to attach to the leaves and settle more easily in sediments. Seagrass also serves to reduce the energy of waves and currents moving towards the shore. The role of seagrass in trapping microplastics was evidenced by the difference in the abundance of microplastics in sediments in areas with and without seagrass [12, 14]. In this study, microplastics were relatively more abundant in seagrass sediments at the three stations, although this difference was not significant ($p = 0.066$). Other studies have also reported that seagrass does not play a significant role in

trapping microplastics [5, 35, 36]. The size of the plastic, characteristics and conditions of the location, and seagrass characteristics can lead to variations in the distribution of microplastics in sediments [35].

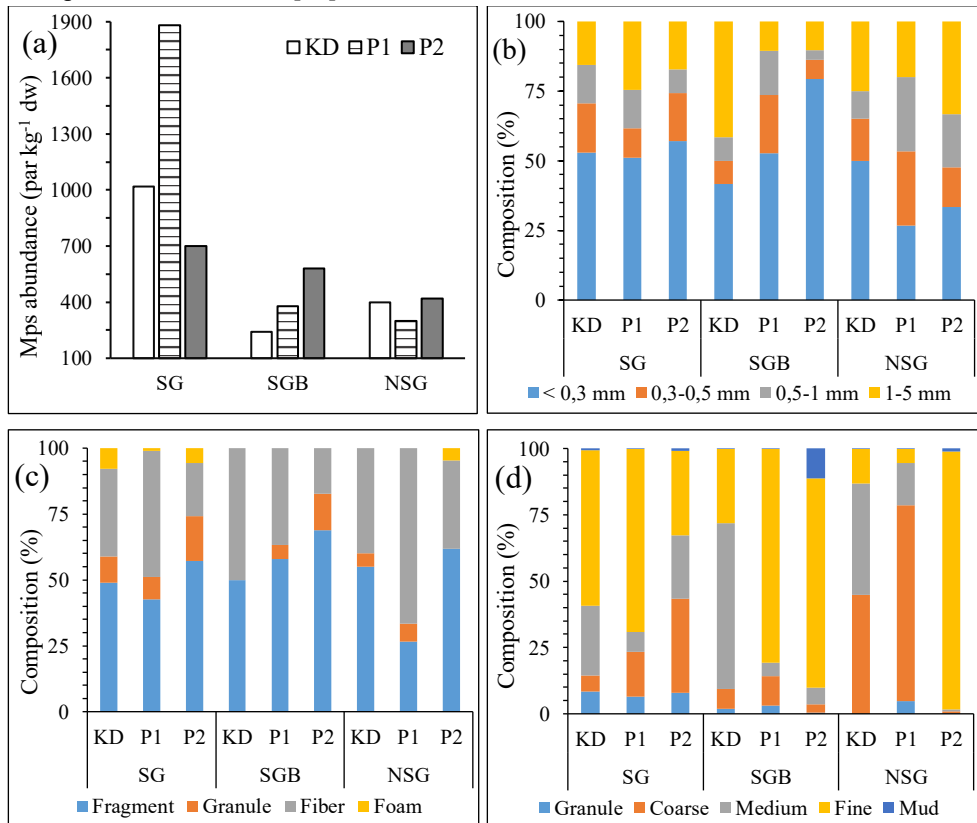


Fig. 2. Total abundance of microplastics (a), size (b) and shape (c) composition of microplastics, and the sediment composition (d) of Panjang Island water. SG: seagrass area, SGB: seagrass boundary, NSG: non-seagrass.

Table 1. Comparative assessment of microplastic abundance in sediments from regions of Indonesia.

| Location (origin) | Abundance (par kg ⁻¹ dw) | References |
|---|-------------------------------------|---------------|
| Panjang Island (seagrass and bare flats) | 240–1,880 | This research |
| Panjang Island (mangrove) | 2,130 | [15] |
| Jakarta Bay (riverbed in Pluit and Ancol) | 18,405–38,790 | [30] |
| Surabaya (mangrove and urban coast) | not detected–598 | [31] |
| Surabaya (estuary and coast) | 92–590 | [37] |
| Pramuka Island (seagrass) | 20–440 | [32] |
| Banten Bay (coast) | 267±98 | [4] |
| Benoa Bay (mangrove and coast) | 9.51–90.60 | [38] |
| Muara Angke (mangrove and bare flats) | 28.09±10.28 | [22] |
| Pekalongan (river estuary) | 770–1,010 | [39] |
| Mare Island (seagrass) | 17,000–37,000 13,839–30,666 | [40] |

The source of microplastics in the sediments of Panjang Island may not be local, but rather carried by currents and winds or macroplastics that have washed ashore from other locations and fragmented to form microplastics[41]. During observation, it could be seen that macroplastics were stranded across the coast of southwestern part of Panjang Island. Additionally, the marine debris trajectory in Banten Bay showed macrodebris originating from the Sunda Strait, which has the potential to be transported by surface currents to the coast of Bojonegara and the western coast of Panjang Island, especially during the western monsoon[16]. The relatively calm conditions in the southwestern part of the island may also cause plastic waste to become trapped, fragmented, and form microplastics because of the possibility of a higher deposition rate of microplastic particles. However, a dynamic environment can accelerate plastic fragmentation and microplastics accumulation in sediments [42].

3.2 Characteristics of microplastic

3.2.1 Size of microplastics

The size of microplastics found in the sediments of Panjang Island ranged from <0.3 to 5 mm, with the dominant size class across all stations being <0.3 mm (**Fig. 2b**). Smaller microplastics were found at the seagrass and seagrass vegetation boundaries. This is in line with the results of studies [19, 22] that found that small microplastics were more prevalent in sediments covered by mangrove and seagrass vegetation. Small microplastics affect their transport to locations farther from the source [43]. Therefore, the presence of seagrass may trap smaller microplastics, leading to a relatively higher composition of this microplastic size in seagrass beds. In addition, biofouling can also increase the density of microplastics, making them easier to settle [4, 13].

3.2.2 Shape of microplastics

Microplastics in the sediments of Panjang Island were dominated by fragments and fibers (**Fig. 2c**). Fragments comprised more than 25% of the total composition of microplastic forms in each sediment, followed by fibers, while foam and granules were only found in a few samples. These findings are in line with [15] those of a study by Panjang, who found a dominance of fragments and fibers. The high number of fragments may originate from the large amount of macroplastics found on the coast of Pulau Panjang [18], whereas microplastic fibers may originate from textile waste carried by liquid waste discharge from residential areas [44] and fishing activities [26, 40] around the island. Mechanical degradation and photodegradation processes lead to the formation of microplastic fragments in the environment [31]. Floating macroplastics in water are thought to contribute to the high number of fragmented microplastics [1].

3.3 Sediment composition

The sediment grain size in the waters of Panjang Island tends to be dominated by medium and fine sand fractions (**Fig. 2d**). Finer sediment grains were found to be more abundant in the seagrass sediments and seagrass vegetation boundaries. The high composition of fine grains characterizes relatively low-energy environmental conditions that support sediment deposition. The grain size of sand in seagrass sediments is generally relatively finer, both in areas covered with seagrass and in seagrass beds that are not covered with seagrass, [45]

because the canopy that forms can reduce the potential for sediment resuspension from the seabed [13].

Sediments in the northern waters of the island are coarser than those in the southwestern waters of the island. The northern part of Panjang Island, which faces the open sea and wind, creates more dynamic hydrodynamic conditions. This is thought to determine the sediment transport patterns in this region. Finer sediment fractions are transported to the open sea, leaving coarser sediments that settle more easily to the bottom of the water. Therefore, particle deposition is more difficult in the southwest area, where it is protected by the Panjang Island land mass [46], especially around the western and southern areas of Panjang Island.

3.4 Relationship of microplastic and sediment grain size

Variations in sediment grain size and composition influenced the abundance of microplastics in sediments [47]. Very fine sand showed a moderate positive correlation with microplastic abundance ($r_s = 0.58$), whereas coarse sand showed a very weak negative correlation ($r_s = -0.08$ and -0.20) (Table 2). These results suggest that finer grains favor higher microplastics accumulation. Lower porosity and stronger bonds between fine sediments enhanced the retention of microplastics in the surface sediment [48].

Table 2. Spearman coefficient between sediment grain size and microplastic total abundance in Panjang Island.

| Sediment grain size | Microplastic abundance |
|---------------------|------------------------|
| Granule | 0.483 |
| Very coarse sand | -0.083 |
| Coarse sand | -0.200 |
| Medium sand | -0.183 |
| Fine sand | 0.450 |
| Very fine sand | 0.583 |
| Mud | 0.400 |

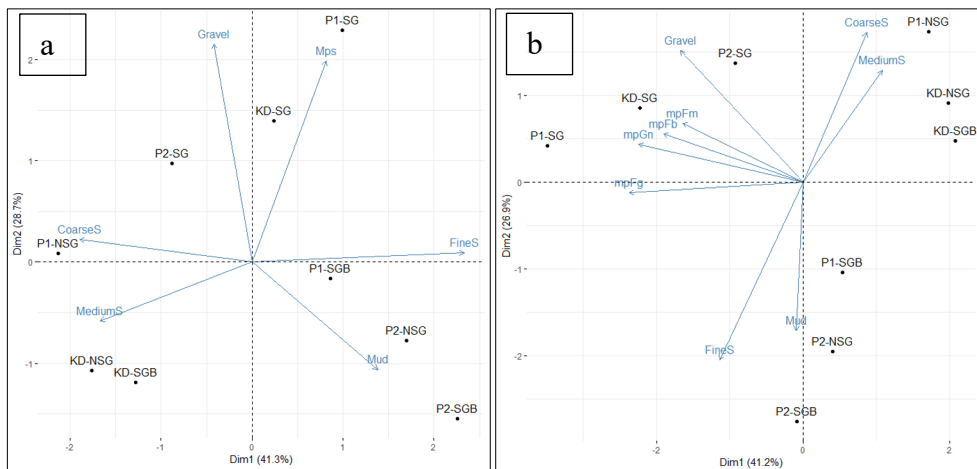


Fig. 3. PCA biplot graph of total abundance of sediment grain size, (a) microplastic abundance and (b) microplastic shape. CoarseS: coarse sand, MediumS: medium sand, FineS: fine sand, Mps: Microplastic abundance, mpFm: foam, mpFb: fiber, mpGn: granule, mpFg: fragments.

The association between sediment grain size with microplastic abundance and microplastic shape was analyzed using PCA. Two principal axes were generated in each analysis, explaining 70.0% (41.3% and 28.7%) and 68.1% (41.2% and 26.9%) of the total sample variance. In PCAa (**Fig. 3a**), Axis 2 was strongly positively correlated with gravel (0.89) and microplastic abundance (0.82), whereas Axis 1 showed strong positive correlations with fine sand (0.96) and mud (0.57) and negative correlations with coarse sand (-0.78) and medium sand (-0.69). Among the sampling sites, stations P1-SG and KD-SG were strongly associated with Axis 2, which corresponded to high microplastic abundance. However, the remaining seven stations were scattered across both axes without clear grouping. This indicates that sediment grain size composition was not the dominant factor influencing microplastics distribution in the sediments of Panjang Island.

PCAb (**Fig. 3b**) shows that the microplastic shapes (fragment, granule, fiber, and foam) were strongly associated with Axis 1 (-0.95, -0.90, -0.76, and -0.66, respectively). In contrast, the sediment grain sizes (coarse sand, medium sand, fine sand, and mud) exhibited stronger associations with Axis 2 (0.69, 0.52, -0.82, and -0.69, respectively). The distribution of sampling stations did not show a consistent association pattern among microplastic shapes. Similar to PCAa, the seagrass stations (P1-SG and KD-SG) were also associated with microplastics with different particle shapes. However, no clear grouping of sampling stations was observed, indicating an inconsistent relationship between microplastic shape composition and sediment grain size.

The results obtained did not clearly explain the relationship between microplastics and sediment grain size [49]. Other studies have also found no correlation between total microplastic abundance and sediment grain size [47, 50]. Nevertheless, other factors may influence the spatial distribution of microplastics in the sediments. The seagrass stations (P1-SG and KD-SG) showed an association with total microplastic abundance and shape, suggesting that seagrass habitats might influence the accumulation and distribution of microplastics in the sediments of Panjang Island. In addition to the presence of seagrass, other factors, such as hydrodynamic conditions and other sediment characteristics, may also play a role in shaping the microplastic distribution in sediments [51]. For instance, sediments can resuspend and release microplastics into the water column under dynamic or high flow velocities [52]. The differences found between studies could also be due to differences in the sediment grain size classification [24]. Therefore, further investigation of the environmental conditions at the sampling sites is recommended.

4 Conclusions

This study found microplastics in the sediment of Panjang Island, Banten. Microplastic abundance ranged from 240 to 1,880 par kg⁻¹ dw with varying shapes and sizes. Fibers, fragments, and small microplastics were the dominant MPs. The sediment composition varied spatially, with coarser grains in the north and finer sediments in the southwest, likely influenced by local hydrodynamics. This is thought to be related to the dynamic conditions in the northern region. A moderate positive correlation was observed between microplastic abundance and very fine sand, whereas PCA results indicated an association between microplastics and seagrass stations. These findings indicate that seagrass may contribute to the retention of microplastics, resulting in a higher abundance within seagrass-associated sediments. Therefore, further investigations considering coastal vegetation and hydrodynamic factors are recommended.

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