Journal of Oceanology and Limnology
Vol. 44, No. 2, pp. 693-705, 2026
https://doi.org/10.1007/s00343-025-5027-y

Research Paper

Distribution of microplastics in mangrove sediments: role of biogeomorphology*

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Received Jan. 21, 2025; accepted in principle Apr. 28, 2025; accepted for publication Jul. 8, 2025

Abstract Biogeomorphic features are common in mangrove ecosystems worldwide, particularly crab burrows, which play a vital role in shaping regional material cycling processes. This study provides new insights into the distribution and indicators of microplastics in mangrove sediments by examining the role of biogeomorphology, specifically by investigating the distribution of crab burrows and microplastic pollution in the Jiulong River estuary, China. Results show that the abundance of microplastics in the sediments of mangroves in Jiulong River estuary was 286.45±18.98 items/kg (mean±SE). The microplastic distribution showed seasonal variations, with no significant differences among burrow treatments in rainy season but marked differences in dry season (P=0.037; F=3.403). There were significantly fewer microplastics in large burrows than in small burrows, with both burrow types showing substantially lower abundance than non-burrow sediments, especially for particles >500 μm in size. Vertical stratification was observed in dry season only during which microplastic level was lower in deeper sediment layers than in the surface layers of the burrows. Pearson's coefficients highlighted significant correlations between crab burrow density and microplastic abundance in the sampling plots. The crab burrow area index (S_{burrow}) was used to reflect the area occupied by crab burrows, and we found that the index exhibited a highly significant correlation with microplastic abundance (P<0.001; R=0.997). Overall, the specific effects of crab burrows on the distribution of microplastics were highly variable and shaped by the interplay of hydrodynamic conditions, sedimentary environment stability, and burrow characteristics over time and space. Therefore, crab burrows can be used potentially to characterize the microplastic pollution level in mangrove ecosystems. We recommend to incorporate this biomonitoring method into existing coastal environmental assessment framework.

Keyword: microplastics; biogeomorphology; mangrove; crab burrow; Jiulong River estuary

1 INTRODUCTION

Microplastics, defined as plastic particles smaller than 5 mm in size, are originated from various sources: the primary microplastics found in cosmetics and paints, pellets, and flakes used in plastic production; the secondary microplastics generated by the wear of larger items, such as textiles and tires; and the fragmentation of plastic debris in the environment (Thompson et al., 2024). The environmental fate and transport of microplastics are governed by complex interactions between hydrodynamic forces, sediment dynamics, and bioturbation processes, with smaller particles (<1 mm) exhibiting greater mobility across water-sediment interfaces (Jiang et al., 2022; Malli et al., 2022). The proliferation of microplastics has closely followed the increase in global plastic production and consumption since the mid-20th century (Yenney et al., 2024). These particles are widely distributed across diverse environments, including marine, freshwater, and terrestrial ecosystems, and their

* Supported by the Natural Science Foundation of Fujian Province (No. 2022J05278)
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presence has been documented in remote and pristine areas (Li et al., 2018a; Rillig and Lehmann, 2020; Patterson et al., 2022; Rakib et al., 2023; Wang et al., 2023). Microplastics pose a significant risk to wildlife through ingestion, leading to physical harm and potential chemical contamination. This ingestion can adversely affect individual organisms and disrupt trophic interactions, ultimately threatening the ecosystem health and stability (Wang et al., 2021; Jain et al., 2023; Aramendia et al., 2024). Moreover, additives such as plasticizers (e.g., phthalates), flame retardants (e.g., PBDEs), and stabilizers can leach from microplastics during environmental aging, acting as endocrine disruptors and inducing cellular toxicity even at low concentrations (Rochman et al., 2019; Lee et al., 2024). Consequently, microplastic pollution in coastal regions has become a pressing environmental issue that has attracted considerable attention globally (Rakib et al., 2022).

Mangrove ecosystems are of great ecological significance, providing essential services such as coastal protection, carbon sequestration, and habitat for diverse species (Lovelock et al., 2024; Nunes et al., 2024). However, because of their strategic location at the land-sea interface, mangroves are particularly vulnerable to microplastic pollution (Govender et al., 2020). Previous studies have examined the sources, distribution, and ecological impacts of microplastics within mangrove systems, underscoring the urgent need to clarify the patterns and factors that influence their distribution and migration in these vital ecosystems (Liu et al., 2022; Talukdar et al., 2023; Zhao et al., 2024b). These ecosystems are characterized by biogeomorphic features that shape ecological processes, with crab burrows being ubiquitous and integral components (Min and Kathiresan, 2021). Globally observed high burrow densities illustrate their ecological prominence: in China's Huanghe (Yellow) River Delta, *Helice tientsinensis* burrows reach 80 inds./m^2 (Li et al., 2018b), while *Uca speciosa* constructs burrows reach at 92 inds./m^2 in the Bahamas (Rodríguez-Tovar et al., 2014). Research dating back to the 1990s has shown that natural particles, such as organic detritus and fine sediments, can be transported by water flow into crab burrows, where they accumulate on the interior surfaces (Iribarne et al., 1997, 2000). Sediment deposition rates reach 3.87 g/d in Argentinian salt marshes (Gutiérrez et al., 2006), with burrows preferentially trapping fine particles that reduce the internal grain size compared to the surrounding sediments (Murray et al., 2002; Wang et al., 2010). Conversely, burrows facilitate sediment-water column exchange, potentially releasing particles back into aquatic systems (Wang et al., 2010; Xie et al., 2022). This dual function establishes crab burrows as dynamic regulators of material flux in coastal environments.

Previous studies have indicated that the distribution and transport of microplastics in coastal sediments exhibit patterns similar to those of natural detritus (Wu et al., 2020). Consequently, the prevalence of crab burrows may influence the sink-source dynamics of microplastics in the sedimentary environments of mangrove ecosystems. The role of biogeomorphology in the distribution of microplastics in these ecosystems warrants further investigation. In coastal ecosystems, the distribution of crab burrows is often considered an ecological indicator. In addition to reflecting crab population sizes (Pombo and Turra, 2019), these burrows can also indicate levels of urbanization, human disturbance (Hereward et al., 2017; Gül and Griffen, 2018), and overall environmental quality (De Souza et al., 2017). The utility of crab burrow characteristics as ecological indicators stems from their strong association with biotic and abiotic factors in coastal wetland systems, including vegetation distribution, hydrodynamic forces, sediment structure, hardness, and water salinity (Li et al., 2018b; Wei et al., 2024). Notably, these indicators were correlated with microplastic distribution, suggesting a potential link between crab burrows and microplastic dispersal.

Building on previous work, we conducted a case study and examined the spatiotemporal distribution of microplastics and crab burrows within the mangrove ecosystem of the Jiulong River estuary to investigate the potential correlations between these two components. Based on the findings of previous studies, we hypothesized that: 1) the abundance of microplastics may differ between the interior of crab burrows and areas without burrows; 2) the vertical distribution of microplastics will vary between areas with and without crab burrows; and 3) the patterns of crab burrows will exhibit significant correlations with the distribution of microplastics in the sediment. This study aims to strengthen the connection between biogeomorphology and microplastic pollution dynamics in coastal environments, thereby providing further support for coastal ecosystem management.

2 MATERIAL AND METHOD

2.1 Study site and sampling

This study was conducted in the Jiulong River estuary in Fujian Province, China (Fig.1). The Jiulong River, the second largest river in Fujian, has a drainage area of approximately 14 700 km², spanning 13 cities and supporting a population of over five million residents. The Jiulong River estuary is a semi-enclosed macrotidal estuary with an annual mean tidal range of approximately 3.3 m and a maximum tidal range of 6.4 m (Cheng et al., 2020). The region experiences annual average wind speeds ranging 3.9–6.5 m/s (Li et al., 2023b). This subtropical area receives most of its annual precipitation, totaling 1 371 mm, during summer typhoons. The wet season, from April to October, accounts for most of the water discharge, with flow rates varying between 436 and 840 m³/s. In contrast, during the dry season, water discharge decreases significantly, ranging 137–298 m³/s (Li et al., 2021).

The estuarine intertidal zone of the Jiulong River is characterized by extensive mangroves that provide a primary habitat for regional benthic fauna, fish, and waterbirds. Crustaceans dominate the benthic communities, with the most abundant species being *Ocypode stimpsoni* and *Ilyoplax tansuiensis*. In recent years, human activities such as agriculture, aquaculture, and shipping have profoundly impacted the watershed environment. A study by Qian et al. (2024) highlighted that microplastic particles are prevalent in the intertidal sediment of the region, with an average abundance of 265 items/kg.

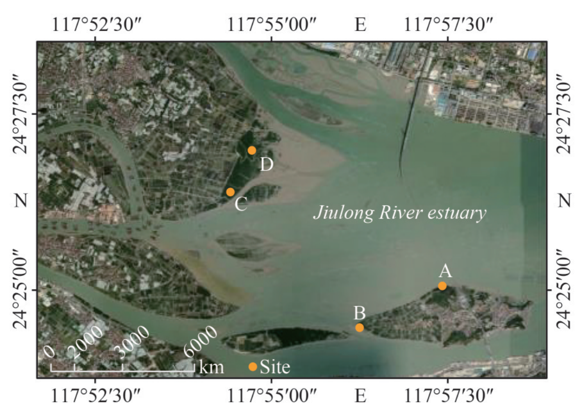

Fig.1 The study sites in the mangrove ecosystems in Jiulong River estuary

The base map includes Chinese provincial administrative boundaries (publicly available from the National Geomatics Center of China) and Google Earth imagery. A: *Kandelia obovata* and *Spartina alterniflora* mixed zone; B: *K. obovata* and *Aegiceras corniculatum* mixed zone; C: *Avicennia marina* zone; D: *K. obovata* zone.

In August 2023, we established four sampling sites across four typical habitats of the Jiulong River estuary to investigate the distribution characteristics of crab burrows and microplastics in the sediment of the intertidal zone (Fig.1). All sampling sites were located 50 m from the dike and were inundated during high tide. At each site, we set up five 1-m×1-m sampling plots parallel to the dike, with an approximate distance of 20 m between the plots.

We conducted two investigations and sampling during both rainy season (August 2023) and dry season (December 2023). In each plot, we initially recorded the density of crab burrows (≥0.5 mm, aggregated across all species) and measured the diameter of openings from 10 randomly selected burrows. To examine the microplastic distribution, we collected three sediment cores (15 cm deep and 5 cm in diameter) from each plot using a stainless-steel split tube sampler. The cores were collected from three distinct locations: one centered on a large crab burrow (diameter >20 mm), one on a small crab burrow (diameter ≤20 mm), and one from an area without any burrows. Each core was immediately extracted and sectioned into two depth layers (0–7.5 and 7.5–15 cm) using a stainless-steel knife. The sediment samples were transferred to clean cylindrical iron containers for further laboratory analysis.

2.2 Sample preparation

Microplastics were extracted from the sediments using a density separation method (Peng et al., 2017; Wu et al., 2020). Twenty grams (accurate to 0.01 g) of each dried sediment sample were placed in a 500-mL beaker. A sodium chloride (NaCl) solution (1.12 g/L) was selected for density-based flotation owing to its cost-effectiveness and broad applicability, with 300-mL aliquots added to each beaker (Wu and Wang, 2022). The sample was thoroughly stirred and incubated in a 60-°C water bath for 36 h to allow the polymers to suspend in the supernatant. The flotation process was repeated thrice. The supernatant was vacuum-filtered through a glass fiber filter membrane with a diameter of 47 mm and pore size of 0.45 μm.

2.3 Microscopy and FTIR analysis

The resulting filtered membranes were examined under a microscope (Saike SK2500H, China) to observe and record the microplastic characteristics.

The shapes and colors of the microplastics were identified based on the classification criteria outlined by Su et al. (2019). The particle sizes were measured using a micrometer. A randomly selected subset of microplastic particles (50% per site, 20-μm–5-mm size range) was analyzed for polymer composition via FTIR (Fourier transform infrared spectroscopy, Thermo Nicolet™ iN™10) in transmittance mode (Wu et al., 2023). The spectral range was set from 4 000 to 675/cm, with a collection time of 3 s and 16 scans per measurement (Jabeen et al., 2017). The objectives of the FTIR analysis were twofold: first, to help confirm that the suspicious particles detected under the microscope were indeed microplastics, and second, to provide insight into the polymer composition of microplastics in the Jiulong River estuary region, further aiding in the determination of their source.

2.4 Quality control measure

To prevent sample contamination, field sampling was conducted quickly, with each core collected in less than 10 s to minimize the potential for secondary contamination. The researchers wore cotton lab coats and gloves to avoid contact with plastic materials. All containers were pre-washed with Milli-Q water, and the solutions were filtered once or twice before use. To ensure no contamination from the laboratory environment, three procedural blanks were included in the analysis, none of which revealed the presence of microplastic particles. Recovery rates were determined to quantify particle losses through experimental procedure. We performed a recovery experiment using 180 particles (including PE, PET, and PP) with a size of ~1 mm. It showed that the average recovery rate for plastic particles is 79.6%±12.6%.

2.5 Statistical analysis

We analyzed microplastic and crab burrow data using IBM SPSS Statistics v.22. We compared the abundance of microplastic among different burrow treatments and sites with Oneway-ANOVA, and using the least significant difference (LSD) for multiple comparison tests. We used *t*-tests to compare the abundance of microplastics between different seasons and also depth layers ($P<0.05$ was considered statistically significant, $P<0.001$ was considered statistically extremely significant) (Wu et al., 2020).

In addition to measuring the density and average opening diameter of crab burrows, we also calculated the Crab Burrow Area Index (S_{burrow}) to quantify the area covered by these burrows:

$$S_{burrow}=B_{burrow}\times d_{burrow}^{2},$$

where B_{burrow} indicated the burrow density of the plots, d_{burrow} indicated the average opening diameter of the plots (Wu and Wang, 2022). We developed a linear regression model to examine the relationship between microplastic distribution and the density, opening diameter, and S_{burrow} of crab burrows.

The terrain map was created using ArcGIS 10.8 software, and the hierarchical cluster analysis was performed using TBtools-II v2.310 (Chen et al., 2023). Other figures were generated using Origin Pro 9.0.

3 RESULT

3.1 Occurrence and composition of the microplastics

Among the 240 sediment samples analyzed, we identified a total of 1 375 microplastic particles. These particles primarily exhibited four shapes: fibers, fragments, foams, and films. The highest proportion of fragments (55.6%) was found in samples collected in rainy season, while both fragments (40.8%) and films (38.9%) were significantly represented in the samples collected in dry season. A total of eight colors of microplastics were detected, with blue, white, green, and transparent plastics being the most prevalent (Fig.2). The average size of the detected microplastics was 927.57±23.81 μm. In both rainy and dry seasons, the most common microplastic size category was particles smaller than 500 μm. Nine types of polymers were detected, with polyethylene (PE), rayon (RA), and polypropylene (PP) being the most prevalent in both the rainy and dry seasons.

Overall, there was no significant variation in microplastic abundance between the rainy and dry seasons ($P>0.05$). However, significant temporal variation was observed at specific sampling sites (A and D). Significant spatial variation among sampling sites was found in rainy season ($P<0.05$) but dry season ($P>0.05$).

3.2 The potential source of microplastics in the mangrove crab burrows

Principal component analysis revealed distinct pollution signatures across three components (Fig.3). The first principal component (PC1), explaining 24.4% of total variance, showed

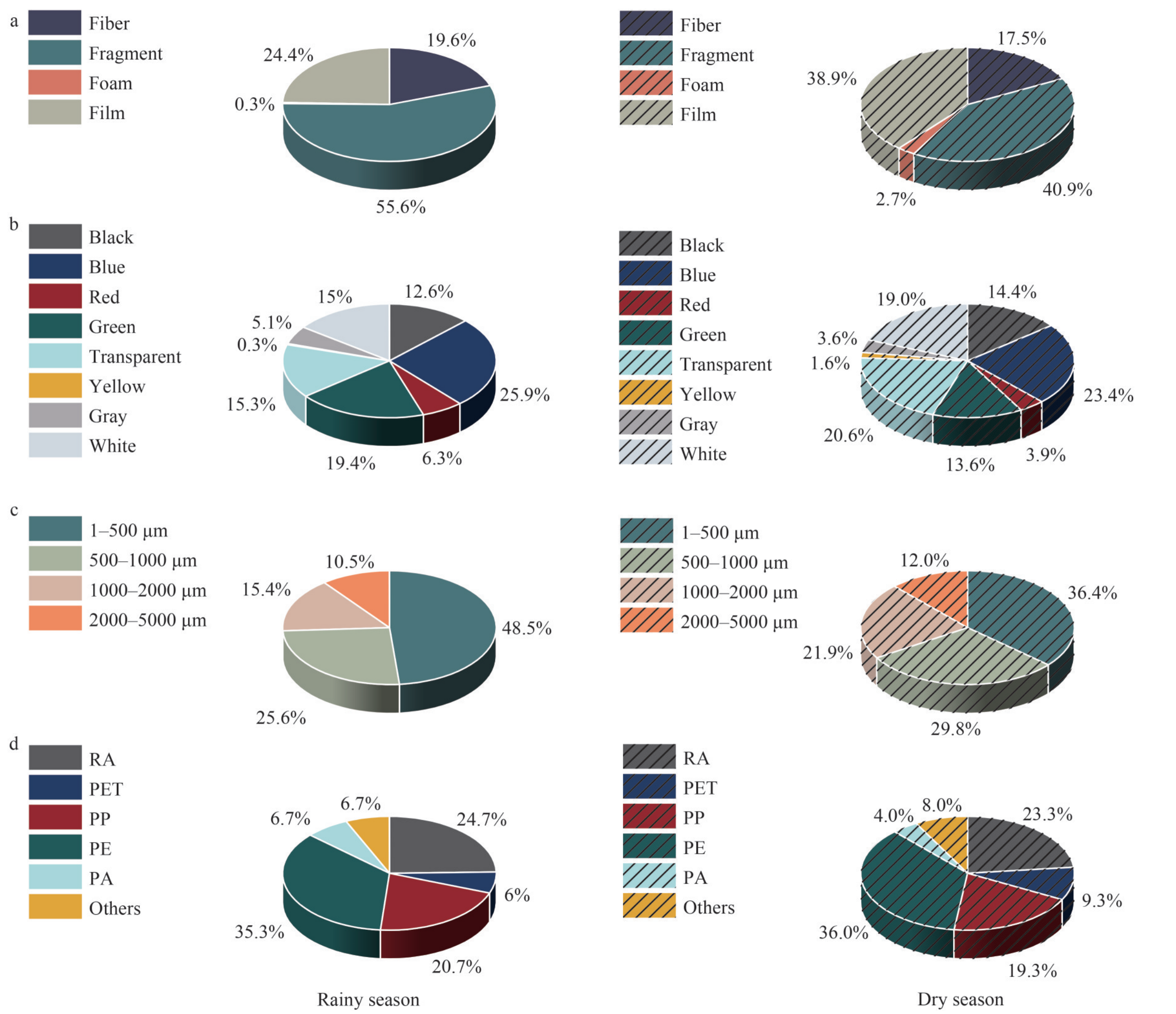

Fig.2 Shape (a), color (b), size (c), and polymer type (d) composition of the microplastics

RA: rayon; PET: polyethylene terephthalate; PP: polypropylene; PE: polyethylene; PA: polyamide; others: cellophane, nylon, polyvinyl chloride, polystyrene. *n* (number of samples)=240.

significant loadings from plastic fragments (0.373), small particle sizes (1–500 μm, 0.376), and blue-colored particles (0.304), collectively indicative of domestic waste discharge and maritime packaging degradation. Further analysis identified PC2 (17.6% variance) as being predominantly associated with fibrous materials (0.426) and black-colored particulates (0.434), patterns consistent with microplastic release from textile laundering processes, fishing gear abrasion, and synthetic fiber deterioration. The third component (PC3), accounting for 10.3% of observed variance, exhibited characteristic loadings for film-type polymers (0.382) and white-colored debris (0.346), reflecting the environmental persistence of agricultural mulch residues and industrial packaging breakdown products. Cluster analysis was employed to examine similar pollution characteristics among the sampling sites and to identify potential plastic sources based on particle shape, color, and size. Results from the Jiulong River estuary identified small particle sizes (1–500 μm), fragments, and blue-colored particles as the primary microplastic sources. Additionally, the distribution characteristics of microplastics (varying by shape, size, and color) were found to be strongly correlated with seasonal variations in estuarine hydrodynamic intensity between the rainy and dry seasons.

3.3 Distribution and characteristic of the crab burrows

Both in rainy and dry seasons, there were significant spatial differences in the densities of crab burrows among the four sampling sites (P<0.05) (Fig.4). Of particular, most crab burrows were

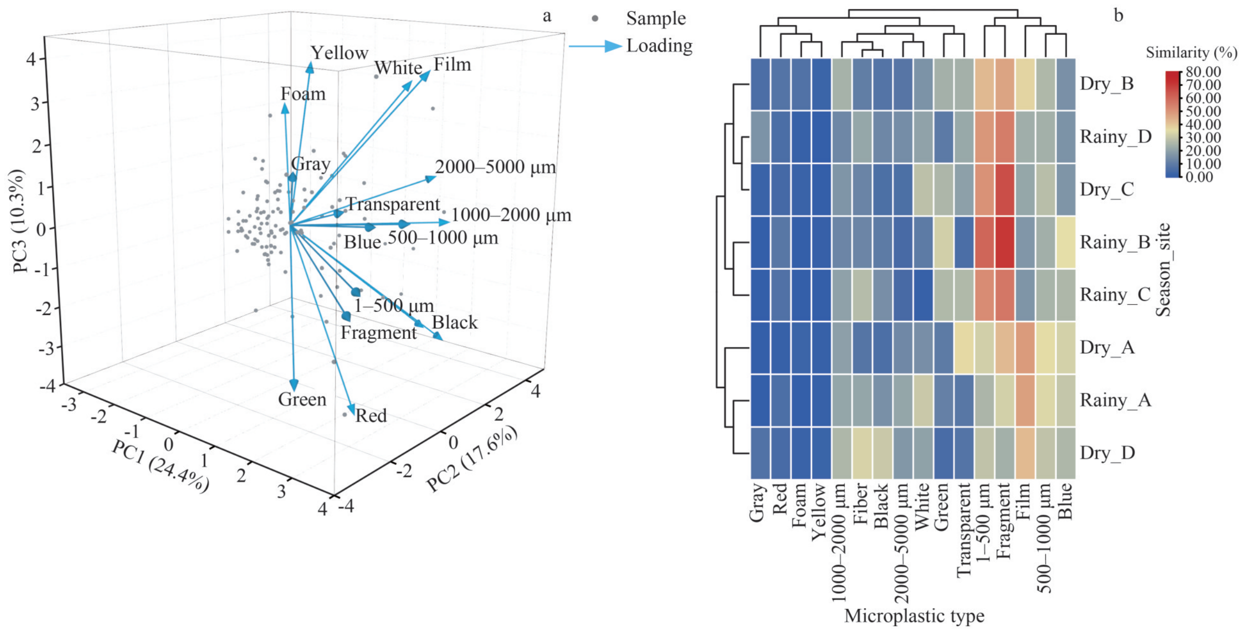

Fig.3 Principal component analysis and hierarchical cluster analysis of microplastics in the sediment of Jiulong River estuary (*n*=240)

a. principal component analysis; b. hierarchical cluster analysis; Rainy_A to Rainy_D denote Sites A to D sampled during the rainy season; Dry_A to Dry_D denote Sites A to D sampled during the dry season. Color intensity indicates the level of pairwise similarity (higher values denote greater similarity).

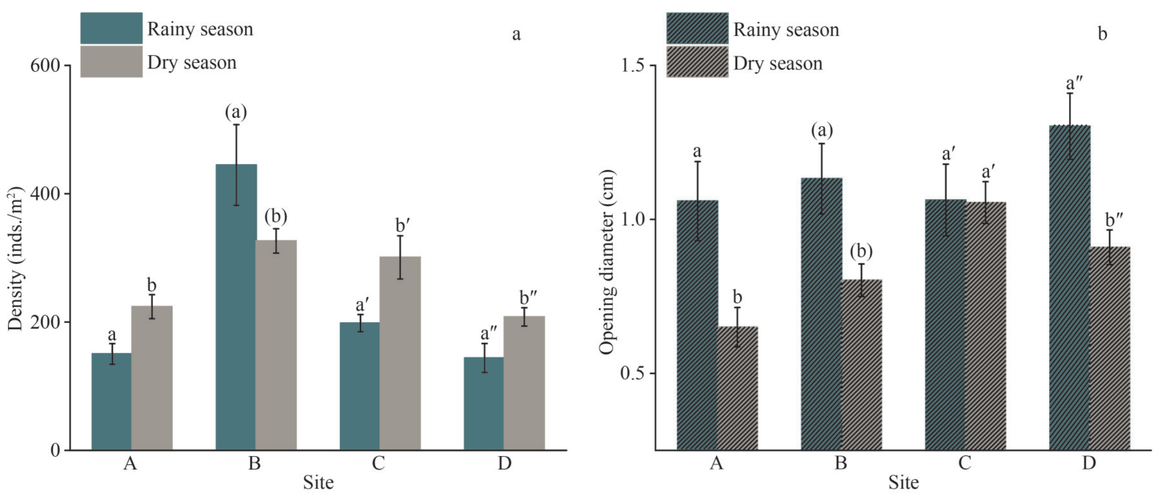

Fig.4 Characteristics of the crab burrows

a. the density of burrows; b. the opening diameter. Columns annotated with the same letter are not significantly different (*P*>0.05, one-way ANOVA, *n*=40), whereas columns with different letters indicate significant differences (*P*<0.05).

recorded in Site B (*P*<0.05). Additionally, significant differences were found in the open diameters of crab burrows among the sampling sites (*P*<0.05). The largest open diameter was observed at Site D during the rainy season, while in the dry season, it was recorded at both Site C and Site D. In most sites, the density of crab burrows increased during the dry season, accompanied by a decrease in the diameter of their openings.

3.4 Distribution of microplastics in different types of the crab burrows

In rainy season, no significant difference in the abundance of microplastics were found among the three treatments based on burrow features (Fig.5). However, significant variations among groups were observed in the dry season samples (*P*=0.037; *F*=3.403). The abundance of microplastics in large burrows was significantly lower than in small

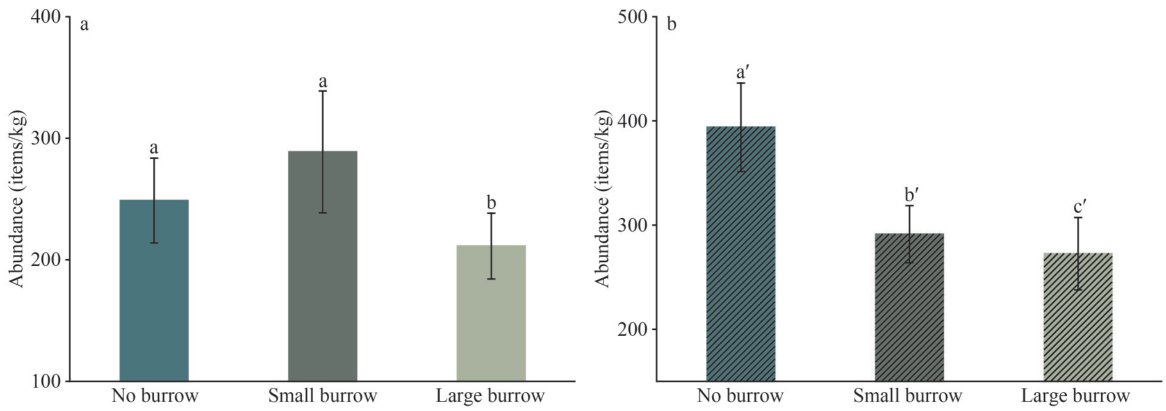

Fig.5 Variations in the abundance of microplastics in different treatments based on burrow features (mean±SE)

a. rainy season; b. dry season. Columns annotated with the same letter are not significantly different (P>0.05, one-way ANOVA, n=240), whereas columns with different letters indicate significant differences (P<0.05).

burrows, and both were markedly lower than in areas without burrows.

In comparing the shape composition of microplastics across different crab burrow treatments, the results indicated that the overall abundance of microplastics decreased in larger burrows, with a more pronounced decline observed in fibers and fragments (Fig.6). Notably, the most significant reduction compared to areas without burrows was seen in particles larger than 500 μm.

The vertical distribution of microplastics in sediments, both inside and outside crab burrows, varied between the wet and dry seasons (Fig.7). During the wet season, vertical stratification of microplastics was not pronounced for any burrow treatment. However, in dry season, both large and small burrows exhibited a significant pattern: the abundance of microplastics in the deeper layers was notably lower than in the upper layers.

3.5 Correlation between the distributions of crab burrows and microplastics

There were no significant correlations between the average opening diameter of burrows and the abundance of microplastics in the sampling plots (Table 1). However, there were a significant correlation between the density of crab burrows and microplastic abundance. The S_{burrow} index, which represents the area occupied by crab burrows, exhibited an extremely significant correlation with the abundance of microplastics within the sampling plots (P<0.001; R=0.997).

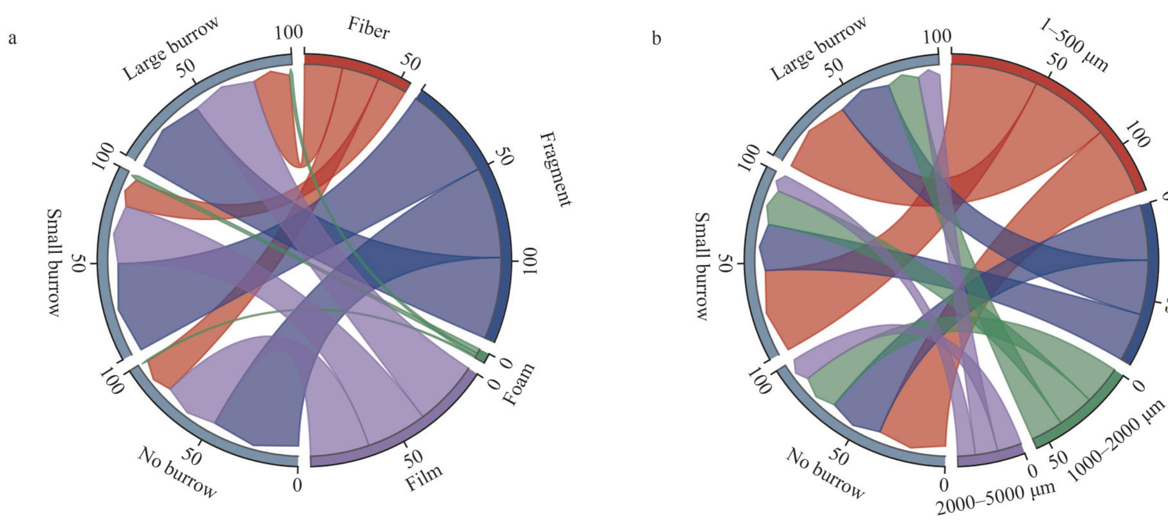

Fig.6 Percentage of shapes and sizes of the microplastics

a. shape; b. size. n=240.

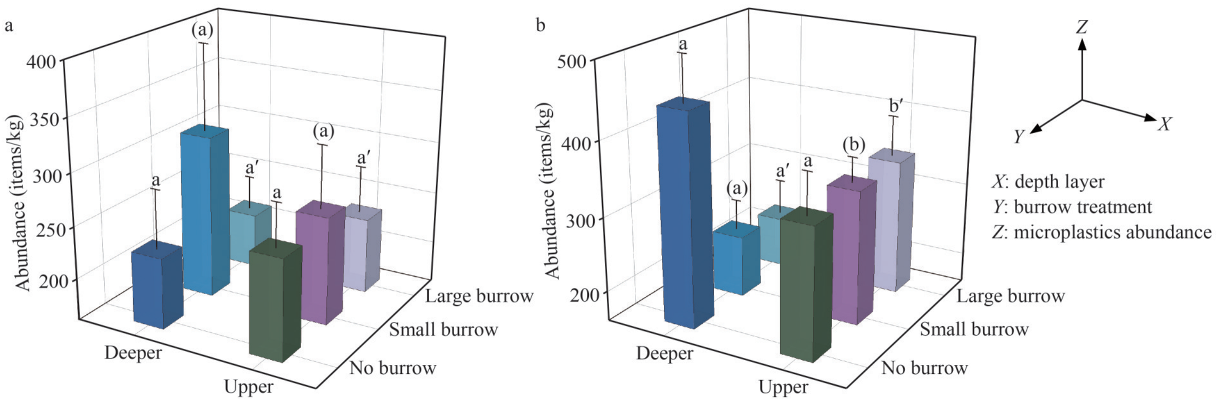

Fig.7 Variation in the vertical distribution of the microplastics

a. rainy season; b. dry season. Any two columns with the different letter are significantly different (P<0.05) (n=240). Columns annotated with the same letter are not significantly different (P>0.05, one-way ANOVA, n=40), whereas columns with different letters indicate significant differences (P<0.05).

Table 1 Correlation coefficients between the burrow characteristics and the microplastics abundance among the sampling plots in Jiulong River estuary

Burrow characteristic	R	P
Density of burrows	0.765	0.027
Opening diameters	0.546	0.419
S_{burrow}	0.997	<0.001

R: Pearson coefficient (n=240).

4 DISCUSSION

Microplastic pollution in coastal regions has become a pressing environmental challenge that has drawn widespread global attention (Paduani, 2020). Historically, research has been limited in examining the relationship between microplastic pollution and biogeomorphic landscapes. Recent research has highlighted a feedback mechanism between mangroves and microplastic particles that parallels the interactions observed between mangroves and sediments (Liu et al., 2022; Xu et al., 2023). These findings are pioneering in exploring the link between biogeomorphology and microplastic pollution. However, crab burrows—abundant and widely distributed biogeomorphology—have largely been neglected regarding their influence on the source-sink dynamics of microplastics in sediment environments.

This study is the first to examine how crab burrows in mangrove ecosystems affect the presence and composition of microplastics. Our first hypothesis was supported by the results. The abundance of microplastic is significant lower within crab burrows and higher in areas without them, suggesting that these burrows play a significant role in modifying the distribution of microplastics in sedimentary environments. Nevertheless, previous studies on salt marshes have found that the abundance of plastic within crab burrows is significantly higher than in areas without burrows, highlighting an inconsistency with our findings (Wu and Wang, 2022). This indicates that the role of crab burrows in the dynamics of microplastics may be variable. They can either trap microplastics to promote deposition or function as conduits that accelerate their release. The underlying mechanisms contributing to this variability are likely influenced by multiple factors. Previous research has highlighted the two-sided role of crab burrows, with some studies demonstrating their ability to trap fine particles and organic debris, while others focus on their contribution to enhancing material exchange between water and sediments (Table 2). Ultimately, the effectiveness of crab burrows may be affected by factors such as hydrodynamic conditions and sediment stability. Furthermore, some studies suggested that the morphology of the burrows themselves may also play a significant role in their functionality (Le Minor et al., 2020). In comparison to research conducted in the Chongming salt marsh (~1.38 cm), the averaged opening diameter of crab burrow in this study are smaller (~0.99 cm), which may account for their reduced capacity to capture sediment particles.

The results also revealed variations in the influence of crab burrows on microplastic distribution between the rainy and dry seasons. During the rainy season, large crab burrows exhibited significantly lower microplastic levels compared to areas without burrows. While in the dry season, both large and small crab burrows showed

Table 2 Previous studies on the effects of crab burrows on particle capture, deposition, and scour

Reference	Study area	Survey subject	Function of burrow
Iribarne et al., 2000	Mar Chiquita coastal lagoon, Argentina	Debris (mainly plastics)	Increases the collection and accumulation of debris
Wang et al., 2010	Chongming Island, China	Sediment	Selectively trap fine particles and high organic matter sediments
Wu and Wang, 2022	Intertidal zone of Chongming Island, China	Microplastic	Significantly increase the capture of microplastics
Botto et al., 2006	Mar Chiquita coastal lagoon, Argentina	Organic matter, sediments	Increase the trapping of organic detritus and fine-grained sediments, as well as the scouring of sandy sediments.
Escapa et al., 2008	Intertidal zone of Bahía Blanca Estuary, Argentina	Sediment	Increase sediment capturing in low-flow habitats and sediment scouring in high-flow habitats
Le Minor et al., 2020	Intertidal mudflat of sub-estuary in Tairua, New Zealand	Organic matter, sediment, and macrofauna	Burrows with low aspect ratios significantly increase the capture of large organic particles, sediment and macrofauna

reduced microplastic abundance relative to non-burrow areas. Prior studies have shown that the intensity of hydrodynamic in intertidal zones experiences considerable variation between these seasons (Aagaard et al., 2006; Harvey et al., 2023). This pattern is similarly applicable in the Jiulong River estuary watershed (Li et al., 2021). Numerous studies have shown that variations in hydrodynamic intensity result in significant differences in microplastic pollution levels within sedimentary environments (Jong et al., 2022; Garcés-Ordóñez et al., 2023). Consequently, it can be inferred that during the dry season, when hydrodynamic activity is reduced, crab burrows play an even more crucial role in influencing the distribution of microplastics. In contrast, during the wet season, the stronger hydrodynamics may partially obscure the effects of biogeomorphology. Additionally, this study highlighted that a higher proportion of fibrous and fragmented microplastics is released through crab burrows, underscoring the role of biological geomorphology in enhancing hydrodynamic connectivity. Fragmented and fibrous microplastics are generally less mobile and less easily suspended than film particles. However, the increased water flow disturbances created by crab burrows could lead to the decrease in the proportion of these two types of microplastics. Due to data limitations, it is challenging to compare the hydrodynamic and substrate conditions in this study area with those of previous research sites. However, this finding is consistent with earlier geomorphological studies that highlight the interdependence of biological, geomorphological, and hydrological processes in coastal regions, where the influence of various factors can fluctuate dynamically (Zhu et al., 2024). Therefore, the impact of crab burrows on microplastic distribution cannot be generalized. Future research should systematically examine the role of biological geomorphology in shaping microplastic pollution in coastal areas, while considering relevant disturbance factors. Given the significant ecological risks microplastics pose to coastal ecosystems (Al Nahian et al., 2022), the role of biogeomorphology in regulating these risks should also be emphasized in future research.

Microplastic pollution displaying vertical stratification in coastal sedimentary environments has been widely reported. Investigations by Zheng et al. (2020) and Yu et al. (2023) suggested that various factors, such as water-sediment exchange and increased anthropogenic activities during the Anthropocene, often lead to higher microplastic abundance in surface sediments compared to deeper layers. However, other studies indicated that this stratification may not consistently occur (Zhao et al., 2024a). This research represented the first investigation into the influence of biogeomorphic landscapes on the vertical stratification of microplastics in sedimentary environments. The findings supported the second hypothesis of this study, suggesting that crab burrows played a vital role in regulating the vertical stratification of microplastics. Notably, these functions of crab burrows also varied between wet and dry seasons: during the wet season, the vertical stratification of microplastics was less pronounced in both burrowed and non-burrowed areas. In contrast, during the dry season, both large and small burrows exhibited significantly higher microplastic abundance in surface sediments compared to deeper layers. This pattern was consistent with the data of overall microplastic pollution levels, indicating that under strong hydrodynamic conditions in the wet season, the vertical distribution of microplastics tended to become more uniform. Conversely, during the dry season, the reduced hydrodynamic activity enhanced the role of crab burrows as conduits between water and sediment. Burrows could facilitate the release of microplastics from deeper sediments into the water column and resulting in more pronounced vertical distribution patterns. Additionally, a previous study has indicated that bioturbation by certain soil organisms can affect the vertical distribution of microplastics in soils. While limited studies have specifically examined the impact of crab activity on microplastic transport, research on organisms such as worms has demonstrated that biota can introduce microplastics into deeper soil layers through burrowing and vertical movement (Rillig et al., 2017). This study did not fully disentangle the effects of bioturbation from those of biogeomorphic influences. Future research could consider employing controlled experiments to isolate the impact of biogeomorphology while minimizing the effects of bioturbation.

In coastal area, the distribution characteristics of crab burrows are often considered an ecological indicator. Beyond simply representing the population size of crabs (Pombo and Turra, 2019), they can also indicate levels of urbanization, human disturbance (Hereward et al., 2017; Gül and Griffen, 2018), and environmental quality (De Souza et al., 2017). This is primarily due to their strong correlation with the parameters they indicate. Furthermore, metrics such as the number and size of crab burrows are generally more straightforward to monitor than the underlying factors they represent. Our findings indicate a significant correlation between the number of crab burrows and the abundance of microplastics in the area. Notably, the S_{burrow} index, which reflects the area occupied by crab burrows, exhibited an extremely significant correlation with microplastic abundance. This raises an intriguing question: could the characteristics of crab burrows serve as indirect indicators of microplastic levels in specific regions? In our previous research on the salt marshes of the Changjiang (Yangtze) River estuary, we also observed correlations between the size and area of crab burrows and microplastic abundance in the intertidal zone.

The attractiveness of using crab burrow characteristics as ecological indicators lies in their close coupling with both biotic and abiotic factors in coastal wetland systems. These factors include vegetation distribution, hydrodynamic strength, sediment structure and hardness, as well as water salinity (Li et al., 2018b; Wei et al., 2024). Notably, these indicators have been proved to correlate with microplastic distribution (Wu et al., 2020; Liu et al., 2022). Therefore, developing models to predict microplastic pollution levels based on the relationship between microplastic abundance and crab burrow characteristics across various regions and ecosystems is a valuable pursuit. This approach may offer greater efficiency compared to traditional laboratory-based methods of microplastic detection. However, it is crucial to recognize that the presence and distribution of microplastics are closely intertwined with human activities and physical processes. Thus, examining the relationship between crab burrows and microplastic pollution necessitates careful consideration of scale and contextual factors. For example, in beaches subjected to significant human disturbance, the number of crab burrows may be influenced by trampling, which could introduce bias into the data (Lucrezi et al., 2009). Therefore, future research should aim to enhance baseline data to support the generalizability of these findings.

This study acknowledges methodological limitations wherein the cost-effectiveness and accessibility of NaCl for density separation are counterbalanced by suboptimal recovery efficiency for high-density polymers (e.g., PET, PVC), potentially compromising environmental microplastic quantification; consequently, future investigations should adopt higher-density alternatives such as NaI or $ZnCl_2$. Furthermore, extant degradation protocols require refinement to minimize physicochemical damage during organic matter digestion, with evidence suggesting 10% KOH as a viable gentler alternative (Prata et al., 2019). Additionally, the intertwined effects of crab burrow architecture and bioturbation processes (e.g., sediment reworking and faunal mobility) remain undifferentiated, necessitating controlled field experiments to delineate their respective ecological contributions.

5 CONCLUSION

This study reveals that crab burrow characteristics (e.g., density and spatial configuration) significantly influence microplastic distribution in mangrove sediments, with seasonal hydrodynamics and sediment stability modulating these effects. Notably, crab burrows act as natural filters, preferentially reducing retention of larger microplastics (>500 μm) and exhibiting vertical stratification during dry seasons. The strong correlation between burrow metrics (e.g., S_{burrow}) and microplastic abundance highlights their potential as bioindicators for pollution monitoring. To mitigate microplastic accumulation, we recommend integrating crab burrow assessments into coastal environmental management frameworks to guide targeted conservation efforts, particularly in bioturbation-active zones. Strengthening source control policies and promoting mangrove habitat stability remain critical complementary strategies.

6 ACKNOWLEDGMENT

Chengyi ZHANG thank the Innovative Training Program of Xiamen University of Technology. We thank reviewers for constructive comments and the journal editors for the improvement of the manuscript.

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