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# Revealing the migration behaviors of microplastics in the intertidal environments

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## 1 Introduction

In January 2020, the novel coronavirus pneumonia (COVID-19) rapidly spread throughout the world. As of the post-pandemic (July 2023), the World Health Organization (WHO) reports 767 million confirmed cases and 6.9 million deaths worldwide, with new variants like Omicron still causing regional outbreaks (WHO, 2025). The WHO recommended taking strict interventions decisively to prevent further spread of COVID-19, such as wearing face masks, washing hands, and staying at home (WHO, 2025). The measures brought about an upsurge in the demand for plastics, especially face masks, single-use dishware, and disinfection supplies. Despite vaccination efforts, the pandemic has generated over 8.4 million tons of plastic waste globally, according to 2022 satellite estimates, primarily from medical equipment and packaging (Peng et al., 2021). This surge disrupted the 2025 global plastic reduction targets outlined in the UN Environment Assembly resolution (UNEA-5.2), as nations prioritized single-use plastics for infection control.

For better management of plastic waste, the Basel Convention on the Plastic Waste Partnership also urged progressive plastic management during the COVID-19 pandemic. However, some plastic wastes are still not disposed of properly and enter the ocean surroundings. The debris can be fragmented and degraded into microplastics (MPs; <5 mm) and nanoplastics (NPs; <1 μm) under the effects of solar radiation, temperature variation, wave slap, and biological interactions (Peeken et al., 2018). With the effect of ocean currents and tides, these micro-(nano-)plastics (MNPs) migrate and accumulate in the intertidal zone, a place with strong land–sea interactions (Lv et al., 2020).

Intertidal zones can be roughly classified as mudflats, sandy beaches, rocky beaches, vegetated marshes, and mangrove swamps (Murray et al., 2019). They are extraordinarily important as they not only provide habitat but also feed organisms. During the pandemic, the OceansAsia organization recorded that masses of various types of face masks washed up on Hong Kong Soko beaches (Figure 1) (Reuters, 2020). These MNPs contain many severe ecological hazards: They adsorb surrounding pollutants, disrupt microbial and invertebrate physiology, and accumulate in food webs, ultimately threatening biodiversity and ecosystem resilience. However, a summary of the interaction between MNPs and the intertidal environment is still very limited and not yet fully understood. Thus, the aim of the study is to determine the interactions between MNPs and intertidal zones with different geological conditions. The study also calls attention to reducing the quantity of mismanaged plastic induced by the COVID-19 pandemic in the future. Overall, this study will be of vital importance during the special period to predict the possible environmental risks brought by coronavirus disease prevention manners.

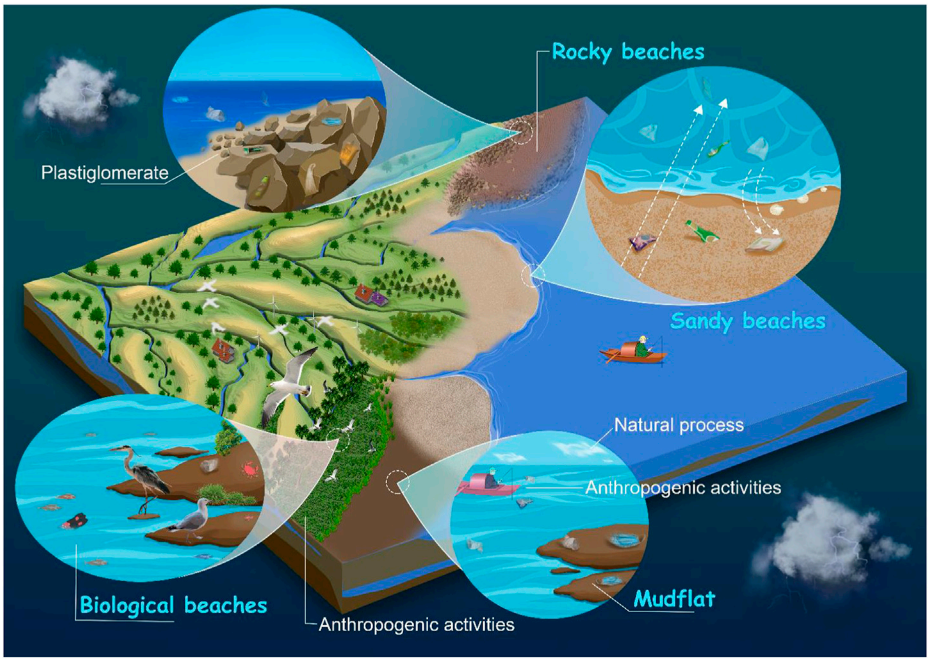


FIGURE 1
Migration of micro-(nano-)plastics (MNPs) in the various intertidal types, including mudflats, biological beaches, rocky zones, and sandy beaches.

## 2 Common migration of MNPs in various types of intertidal zone

Mudflats are often composed of the deposition and accumulation of suspended mineral/organic particulate matter and soluble nutrients in lacustrine, riverine, and estuarine environments (Figure 1). With the exponential usage of plastic during the pandemic, it could be speculated that a large number of MNPs will be discovered due to severe fragmentation that is the result of unique hydrodynamics, strong solar radiation, and human intervention (Wu et al., 2024). Two main routes for the convergence of plastics into the mudflats include natural processes and anthropogenic activities. Natural processes include atmospheric deposition, tidal action, surface runoff, and river transportation (Wei et al., 2024). Anthropogenic activities would be another major route, as mudflats are prime recreational sites. The domestic sewage generated from such activities would increase the secondary outbreak risks by propagating pathogens (Isobe et al., 2019).

As mudflats can supply abundant minerals and nutrients, they serve as a place for numerous plants and are a shelter and nursery ground for many fish and birds (Figure 1) (Li et al., 2020). Biological beaches have also been regarded as hotspots of MNP accumulation after convergence, generating an overlap between MNPs and some species (e.g., zooplankton, invertebrates, crustaceans, fish, seabirds, and even marine mammals) (Wu et al., 2022b). After ingestion, most large microplastics exist in the gastrointestinal tract for several days. However, some of the small MNPs (<100 μm) translocate and induce deterioration in the various systems, such as tissues, digestive, lymphatic, and even the neurological systems (Wu et al., 2022a; Huang et al., 2024). During the whole process, MNPs could release harmful chemicals like additives and even pathogens, such as the release of *Halofolliculina* on plastics, inducing disease outbreaks in organisms (Lamb et al., 2018). It could be hypothesized that the coronavirus attached to such plastics might be the source of multiple outbreaks of the COVID-19 epidemic.

Rocky beaches are where large rock predominates in the coastal zone. Recently, some rocks on beaches have been contaminated by the sink of plastics, defined as "plastiglomerates" (Figure 1) (Das, 2023; Corcoran and Jazvac, 2020). From the geologists' perspectives, plastiglomerates might be a new indicator of the Anthropocene due to their omnipresence and persistence characteristics. Thus, more and more research works have been performed on plastic pollution on rocky beaches (Turner et al., 2019; Das, 2023). Recently, a new effect named "pyroplastic" was reported; it is generated when burnt plastic debris becomes part of an agglomerate with rocks after cooling (Figure 1). The phenomenon has been documented in many beaches, such as Hawaii beaches in the United States and white sand beaches in the United Kingdom. Meanwhile, another contamination, called "plasticrust," was reported to form when the rock surface was encrusted by plastics and formed variable crusts (Gestoso et al., 2019). It has been observed on the mid-upper rocky shore of Madeira Island of Portugal and Giglio Island of Italy. The continuous hydrodynamics induced the crusting between MNPs and rocks in these places. Moreover, the plasticrust phenomenon becomes more severe with increased coverage as time passes (mean ± error bar: 9.46% ± 1.77% in 20 cm × 20 cm quadrants; n = 10) (Gestoso et al., 2019). Unlike "pyroplastic," which is mainly made of polyethylene terephthalate (PET), polyethylene (PE) with blue and white colors is the predominant type of plasticrust contamination. As both PET and PE are mainly used in domestic products, the origins of the two plastic contaminations can be narrowed down to domestic wastes from their corresponding countries.

The latest studies reported that global plastic production increased from 370.7 million tons (Mt) in 2018 (pre-pandemic) to 413.8 Mt in 2023 (post-pandemic) (Zhu and Huang, 2025; PlasticEurope, 2025). Even in the post-pandemic, the public perceptions and attitudes toward health and hygiene practices have changed. Wearing masks in public, which was once considered unusual outside of specific cultural contexts or health scenarios, has now become widely accepted and normalized, resulting in an annual growth rate of approximately 10% (Zhu and Huang, 2025). Thus, coastal marine debris monitoring and action plans might consider plastiglomerate contamination in their marine environmental monitoring guidelines.

Sandy beaches are landforms alongside the sea composed of loose particles. MNP transportation is easily affected by changing ecological conditions, such as tides, winds, waves, and thermohaline gradients (Figure 1). Drifting behavior is very common and hypothesized as a comprehensive response to tide and wind speed. Thus, the three-dimensional oil spill model was found able to well simulate and predict the drifting track of MNPs (Isobe et al., 2014). Some low-density MNPs (<1.00 $g \cdot cm^{-3}$) are easily carried into the marine environment due to wind- and wave-induced currents and roll structures. The repeated MNP migration continues according to their sizes (Hurley et al., 2018). Small-size MNPs have the opportunity to escape from the offshore trapping and enter the open sea, while large-plastic debris is selectively conveyed onshore again by a combination of Stokes drift and terminal velocity (Seeley et al., 2020). Meanwhile, the migration of MNPs according to their density (1.00–1.03 $g \cdot cm^{-3}$) could be influenced by the thermohaline gradients. Some MPs with higher density (>1.03 $g \cdot cm^{-3}$) tend to settle and concentrate in benthic environments (Seeley et al., 2020). Most MNPs are gradually buried by turbulence and persist in the deepest depth in the sandy sediments (Wu et al., 2022b). However, the mechanisms for MNP burial are still unclear and also need more numerical simulation and experimental results. Nowadays, the numerical parameters set in simulating the migration of MNPs are mainly based on experience or publications. Therefore, future studies are needed to enhance the accuracy of the parameter setting by combining laboratory studies and field investigations.

## 3 Conclusion and perspectives

The intertidal zone, especially the mudflats, rocky shores, and sandy beaches, has been severely contaminated by the upsurge of plastic waste. Mudflats as “plastic sinks” concentrate MNPs up to 10 times more than sandy beaches due to their nutrient-rich sediments and dynamic hydrodynamics (Lo et al., 2020). Notably, virus-laden MNPs could be adsorbed onto organic matter, creating pathogen reservoirs. Conversely, rocky shores show concerning geochemical changes: “plasticrusts” (dominated by PE/PET) and pyroplastics (derived from PET) on coastal rock surfaces, enshrining pandemic plastics into geological archives with half-lives exceeding centuries (Das, 2023). Sandy beaches serve as “sorting engines” because low-density MNPs (<1.0 $g/cm^3$) re-enter marine circulation via Stokes drift, while denser particles infiltrate benthic food webs, with 22% of crustaceans showing neurotoxic amounts of nanoplastics (Huang et al., 2024). The findings underscore an urgent change: intertidal zones are active mediators of plastic–pathogen feedback loops. To address what we call the “Anthropocene Boomerang Effect”—plastics are now endangering global health through ecological feedback loops—it is necessary to redefine coastal monitoring frameworks by incorporating artificial intelligence-driven techniques for creating plastiglomerate mapping and tidal hydrodynamic models.

## Author contributions

QH: Writing – original draft. KT: Writing – review and editing. YL: Funding acquisition, Supervision, Writing – original draft, Writing – review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

## Publisher’s note

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