

# Physical Controls on Microplastic Retention in Estuarine Systems: Interactions Between Hydrodynamics, Stratification, Bathymetry, and Particle Properties

Paisley Robles

*Palo Alto Senior High School, 50 Embarcadero Rd., Palo Alto, CA 94301, United States*

## ABSTRACT

Microplastics, introduced into estuaries through riverine discharge, wastewater, and surface runoff, have become a growing environmental concern due to their persistence and potential impacts on aquatic ecosystems. Understanding the mechanisms governing their transport and retention is important for predicting their accumulation and ecological effects. While estuaries are recognized as key zones for microplastic retention and export, existing studies often focus on individual processes or sites, leaving a limited, integrated understanding of how estuarine physical dynamics control microplastic fate. This review aims to synthesize current research to address this gap by examining how estuarine hydrodynamics, stratification, bathymetry, and particle characteristics interact to govern microplastic retention and export. Tidal asymmetry drives net landward transport under flood-dominated conditions, while ebb-dominated tides increase seaward export; residual circulation concentrates sinking particles near the bed and transports buoyant plastics at the surface. Stratification decreases vertical mixing, creating discrete layers that trap particles and promote estuarine turbidity maxima, with stronger freshwater inflows increasing the retention of dense particles and marginally buoyant microplastics more likely to escape during high discharge. Bathymetric complexity, including channels, shoals, and constrictions, localizes particle convergence and creates lateral segregation, with narrower estuaries being more prone to retention and wider systems promoting export. Particle density and biofouling modulate these effects: spherical sinking plastics often track sediment dynamics, while fouling can increase retention of previously buoyant particles. Altogether, microplastic fate is highly system-dependent, influenced by interactions between estuarine morphology, flow dynamics, and particle properties, as many transport processes are highly location-specific.

**Keywords:** Microplastics; Estuaries; Particle Retention; Sediment Transport; Tidal Asymmetry; Stratification; Bathymetry; Estuarine Turbidity Maximum

---

**Corresponding author:** Paisley Robles, E-mail: paisleyrobles@gmail.com.

**Copyright:** © 2026 Paisley Robles. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Accepted** January 6, 2026

<https://doi.org/10.70251/HYJR2348.41263269>

## INTRODUCTION

Microplastic pollution is a growing environmental concern, with particles detected across marine, freshwater, and terrestrial systems (1, 2). These plastics range from microbeads in personal care products

to fragments of larger debris, in reflection of both widespread use and inadequate waste management (3). Transported primarily via rivers, microplastics accumulate in estuaries, where freshwater and marine processes interact to influence their fate. Estuaries are particularly important because they link rivers to the ocean. Their complex hydrodynamics and morphology create conditions that concentrate and trap particles, making them hotspots for microplastic accumulation. However, despite increasing documentation of microplastics in estuarine environments, there remains a limited mechanistic understanding of how estuarine physical processes collectively control whether microplastics are retained or exported to coastal waters. This gap limits our ability to predict microplastic accumulation and assess their ecological impacts.

This review addresses this gap by synthesizing current knowledge on how estuarine physical properties influence microplastic transport and retention. Four factors are considered: hydrodynamics (specifically, tidal asymmetry and vertical mixing), stratification and density-driven circulation, bathymetry and the shape of the estuaries, and particle properties (density and biofouling). While previous studies and reviews have often examined these processes in isolation, few have integrated them to evaluate their combined influence on microplastic fate within estuaries. Drawing on laboratory experiments, field observations, and numerical models, the paper identifies the processes most critical to microplastic transport and retention. Understanding these interactions is necessary for improving predictions of microplastic fate and informing strategies to reduce their flow from estuaries to coastal environments.

This review is based on a targeted literature search of 25 peer-reviewed academic studies, the majority of which published between 2000 and 2024. Sources were retrieved from databases such as Google Scholar, Web of Science, and Scopus. Studies were included if they examined physical mechanisms of particle transport or retention in aquatic systems. Both sediment-focused and microplastic-specific studies were considered, as sediments can be used as analogs for spherical microplastic behavior (4).

To organize the literature, each study was classified by its primary focus: hydrodynamics, stratification, bathymetry, or particle properties. Within each category, notes were recorded on research methods, main findings, and implications for microplastic fate. This approach allowed for synthesis across disciplines and identification of areas where findings are limited.

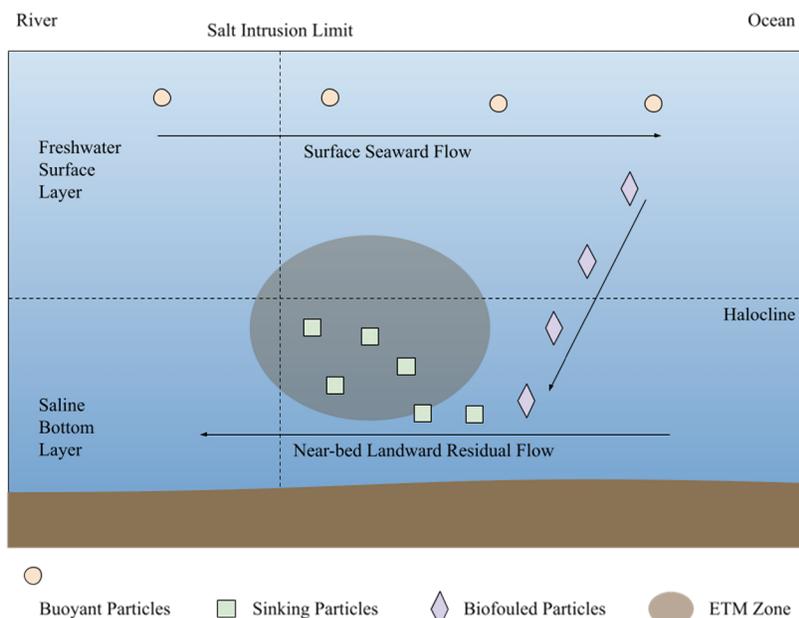
## **HYDRODYNAMICS: TIDAL ASYMMETRY AND VERTICAL MIXING**

Hydrodynamics in estuaries is governed primarily by tides, river inflow, and their interaction with local bathymetry. These processes control the transport, resuspension, and retention of both sediments and microplastics, creating spatial and temporal variability in particle fate. Tidal asymmetry and vertical mixing are especially important in determining whether particles are retained within estuaries or exported to coastal waters.

Tidal asymmetry arises when flood and ebb tides differ in strength or duration. In flood-dominated estuaries, when water flows landward from the ocean into the estuary, particles are preferentially transported landward, promoting accumulation and trapping within the system (5). Ebb-dominated conditions, when water flows seaward back toward the ocean, however, increase seaward export and reduce overall retention (5). Tidal asymmetry can also generate residual sediment transport, a phenomenon in which net landward flux near the bed occurs despite strong advective outflow, a process known as “sediment pumping” (6) (Figure 1). Numerical simulations and field studies indicate that tidal straining can significantly enhance the landward transport of sinking microplastics, sometimes matching or exceeding the magnitude of residual advective flows (6).

Residual circulation further modulates these patterns. Near the bed, net landward residual flows trap sinking particles in convergence zones, often associated with channel or shoal features (7). At the surface, buoyant particles may be advected seaward in surface outflow layers, particularly during periods of high river discharge (8) (Figure 1). These interactions create spatial heterogeneity, where some reaches of an estuary act as long-term particle traps while others function as export zones (5). Tidal asymmetry often interacts with bathymetry to localize convergence and reinforce retention, for example, when channels funnel particles into narrow zones while adjacent shoals experience weaker flux (9).

Temporal variability in tidal forcing is also critical. Spring-neap cycles modulate both the magnitude of tidal asymmetry and the strength of residual currents, leading to periodic shifts in particle retention and export (7). Seasonal changes in freshwater inflow further alter residual circulation patterns, demonstrating that tidal asymmetry must be considered alongside discharge variability to understand estuarine microplastic dynamics fully (10).



**Figure 1.** Physical Controls on Microplastic Transport in Estuaries.

These temporal shifts in circulation interact with vertical mixing processes to determine particle fates. Vertical mixing driven by turbulence from tidal currents and wind influences the resuspension, distribution, and eventual fate of particles (6). Strong tidal mixing can resuspend settled particles, preventing permanent deposition and maintaining high concentrations of suspended sediments or microplastics (11). For sinking plastics, vertical mixing delays deposition by redistributing particles throughout the water column, increasing residence times (10). Buoyant particles, by contrast, can be forced below the surface into regions influenced by density gradients and near-bed flows, changing transport pathways and retention zones (12).

The efficiency of particle retention depends on the balance between vertical mixing and stratification. Stratification occurs when layers of water with different densities form distinct vertical zones that resist mixing. Stratification is typically caused by variations in salinity or temperature. Well-mixed conditions weaken density gradients, increase vertical exchange, and reduce the stability of retention zones (10). In contrast, stratified conditions decrease turbulence and vertical exchange, and promote the formation of stable particle traps, often near haloclines (13). Numerical modeling and field observations indicate that subtidal currents induced by freshwater buoyancy can enhance retention of sinking

particles, particularly under stratified conditions (10). Together, these processes demonstrate that particle fate is dynamic and controlled by the interaction of hydrodynamics and density structure within the estuary.

## STRATIFICATION

Stratification refers to the layering of water masses in an estuary due to density differences, primarily from salinity gradients (14). By decreasing turbulence, particularly during ebb tides, stratification reduces vertical mixing and increases trapping of suspended particles in discrete layers of the water column (15). This vertical structure often produces retention zones near the halocline, where sharp salinity changes occur, and is important in the development of zones of elevated suspended sediment concentrations, Estuarine Turbidity Maxima (ETMs) (13, 16).

Stratification reduces mixing near the halocline, where vertical salinity gradients are strongest (17). This vertical separation allows particles to remain suspended within density layers for extended periods (17). Salinity-induced suppression of turbulence reduces resuspension, concentrating particles in zones of weak mixing (16). Additionally, density-driven circulation reinforces trapping: bottom layers with landward residual flows favor retention of sinking particles, while surface outflow

layers carry buoyant particles seaward (10) (Figure 1).

An important manifestation of stratification is the formation of ETMs, typically located near the landward limit of salt intrusion. These regions are hotspots for particle accumulation, both for sediments and microplastics (16) (Figure 1). Suspended particles can increase local density, which reinforces stratification and sustains turbidity maxima (18). This positive feedback loop allows ETMs to persist even under variable hydrodynamic conditions. ETMs are therefore both a cause and an effect of stratification (18).

Strong stratification constrains buoyant and sinking particles to distinct flow regimes. Buoyant plastics are retained in surface layers, where they are more susceptible to seaward transport by outflowing freshwater (8, 10) (Figure 1). Sinking or denser plastics accumulate in the bottom layers, where residual landward circulation increases retention (10) (Figure 1). This separation produces a vertical partitioning of particle fates, which varies with the strength of salinity gradients and discharge conditions.

The intensity of stratification depends on freshwater inflow and tidal forcing. High discharge intensifies salinity gradients, reinforcing the vertical density barrier and strengthening separation between surface and bottom flows (18). This condition favors retention of sinking particles but may accelerate export of buoyant particles that are isolated at the surface (18). Conversely, low discharge or strong tidal mixing weakens stratification, enhances vertical exchange, and reduces trapping efficiency (18).

Temporal variability, as discussed in the previous section, further modulates stratification. Spring-neap tidal cycles periodically alter the balance between mixing and stratification, changing the intensity and location of ETMs (19). Seasonal changes in freshwater inflow similarly determine whether stratification increases particle retention or promotes export of marginally buoyant plastics (10).

The role of stratification in retention is system-dependent and remains debated. Some field and modeling studies discuss its stabilizing effect, emphasizing longer residence times under strong density gradients (16). Others show that high discharge can promote seaward export by isolating buoyant particles at the surface, or that tidal mixing can override stratification altogether (6, 18). These inconsistencies in variable significance suggest that stratification interacts with hydrodynamics and bathymetry in ways that vary between estuaries, making its contribution to microplastic retention context specific.

## **BATHYMETRY**

The shape and depth of an estuary's seabed exert strong control over circulation patterns, residual flows, and particle transport. Bathymetric features such as channels, shoals, bends, and constrictions generate spatial variability in currents, creating zones of localized retention or increased export (20). These features interact with tidal asymmetry, stratification, and river discharge, determining whether microplastics accumulate or are transported seaward (20).

As discussed, many estuaries exhibit lateral separation in particle transport (21), a phenomenon further modulated by the estuary's bathymetric features. Deep channels often carry net landward residual flows that favor the retention of sinking particles near the bed, while shallower shoals tend to experience stronger seaward-directed fluxes, promoting particle export (20). This lateral segregation creates asymmetric distributions of suspended particle concentrations: channels form convergence zones with elevated sediment and microplastic loads, whereas shoals generally have lower concentrations (20). Studies of the Hudson River estuary and similar systems indicate that these lateral differences contribute directly to the formation and persistence of ETMs (20).

Irregularities in estuarine bathymetry, including headlands, bends, and narrow constrictions, strengthen flow convergence and shear (20). These features create traps by combining increased turbulence with limited downstream transport (18), particularly for denser microplastics that behave similarly to fine sediments (4). Bathymetric fronts formed in these areas are often shifting in position and intensity in response to tidal asymmetry and spring-neap tidal cycles (20). As a result, constricted regions can serve as temporary or recurring retention zones, concentrating particles during certain tidal phases and releasing them under others (20).

The overall scale of estuarine morphology also influences particle fate. Narrower estuaries tend to enhance retention because stronger lateral shear and channel-shoal interactions focus residual flows and convergence into discrete zones (8). Wider estuaries, in contrast, dilute these effects across broader cross-sections, increasing the likelihood of particle export (8). Recent modeling studies further indicate that the interaction of estuary width with tidal surface convergence can determine the fate of buoyant microplastics, with smaller systems favoring retention and larger systems favoring seaward transport (8). This

suggests that morphological scale interacts with particle properties as well as hydrodynamic forces to control particle retention.

Bathymetric retention is not static. Seasonal changes in river discharge, freshwater inflow, and tidal forcing can alter the strength and location of convergence zones (20). Subtidal currents driven by negative buoyancy of freshwater, for example, can increase retention in certain channels, while high-flow periods may flush particles from shoals or shallow margins (10). This is significant because it shows that microplastic accumulation areas in estuaries can change with the seasons, meaning retention depends on both the shape of the estuary and changing water conditions, not just fixed topography.

## **PARTICLE PROPERTIES**

Particle properties strongly influence their transport and retention in estuaries. Density, size, shape, and biofouling, the accumulation of microorganisms and algae on particle surfaces that alter their density and buoyancy, determine how microplastics interact with other physical processes of estuaries (22). While sinking particles often show predictable retention patterns similar to sediments, marginally buoyant or irregularly shaped plastics display greater variability, making their fate less certain (4, 10).

For sinking particles, retention within estuaries is consistently very high, with one study reporting >90% retention (10). This strong trapping is attributed to gravitational settling, landward residual circulation near the bed, and convergence zones formed by channels and shoals (10). Increased river runoff enhances retention further by intensifying near-bed salinity fronts and ETMs, both of which act as strong particle traps (10) (Figure 1). As a result, dense or rapidly settling particles usually travel shorter distances downstream and accumulate near river mouths or at the head of salt intrusion zones (10) (Figure 1).

In contrast, marginally buoyant particles exhibit much more variable transport (10). During high river discharge, strengthened surface outflow layers often advect these particles seaward, lowering retention (10) (Figure 1). Under moderate discharge or tidally dominated regimes, however, oscillatory tidal currents and surface convergence zones can prolong their residence (8). Even small shifts in particle density relative to the water, driven by salinity structure or freshwater inflow, can determine whether marginally buoyant plastics are trapped or exported (10).

Dense, spherical microplastics are commonly found concentrated in near-bed convergence zones and retained at high rates, much like mineral sediments (4, 10). By contrast, fibers and films show more variable behavior, aligning with salinity fronts or convergence features but not always settling predictably (23). These differences in results between studies indicate that particle shape introduces additional variability in retention efficiency across estuaries.

Biofouling can shift buoyant particles into the sinking category over time, changing their transport pathways (24). Microbial colonization on plastics, including bacteria, algae, and inorganic particles, can increase particle density or promote aggregation with organic matter, causing previously buoyant particles to sink (24). Once fouled, these plastics are more likely to accumulate in bottom salinity fronts or ETMs, effectively increasing estuarine retention capacity (25) (Figure 1). Although evidence for this process is still limited in estuarine studies, biofouling represents an important mechanism linking intrinsic particle properties with external estuarine retention features.

Particle density remains the dominant trait shaping retention: sinking particles are more likely to be trapped, while marginally buoyant plastics are more sensitive to tidal variability and more likely to be expelled (10) (Figure 1).

## **CONCLUSION**

Estuarine morphology and hydrology strongly mediate retention processes. Narrow channels increase local trapping, whereas wider estuaries may favor export (20). Similarly, differences in freshwater input, tidal forcing, and circulation patterns create system-specific outcomes (7, 10). As a result, predictions of microplastic fate must consider the local context, and findings from one estuary cannot be directly applied to another without careful evaluation.

The literature on estuarine particle retention highlights several consistent patterns, but also reveals notable contradictions and limitations. Stratification exhibits variable influence. In some estuaries, strong density gradients and halocline formation stabilize retention zones, prolonging particle residence times (18). In others, high freshwater discharge or tidal mixing can override stratification, facilitating seaward export of marginally buoyant plastics (10). Stratification is a context-dependent driver rather than a universal mechanism for retention.

Methodological limitations further constrain the current understanding. Laboratory flume experiments, while valuable for isolating mechanisms, often do not capture the complexity of natural estuaries with variable bathymetry and tides. Direct field observations remain limited, particularly measurements of particle fluxes throughout the water column, and temporal variability, such as spring-neap cycles or seasonal discharge, is frequently overlooked. This scarcity reflects the logistical and technical difficulties of working in estuarine environments: strong currents, high turbidity, and salinity differences make it difficult to deploy and maintain sensors or collect representative samples. Field campaigns are also resource-intensive, requiring specialized equipment and repeated sampling over long timescales to capture variability.

While this review synthesizes current knowledge on microplastic retention in estuaries, it is limited by the available literature and the scope of included studies. Certain particle types, environmental settings, and modeling approaches may be underrepresented, and some regional or temporal dynamics remain poorly documented. Furthermore, while sediment analogs are acceptable to infer microplastic behavior, fibers, films, and biofouled particles may still behave slightly differently (4).

Understanding particle retention in estuaries requires integrating multiple interacting controls: hydrodynamics, stratification, bathymetry, and particle properties (8, 15, 18, 20). These drivers do not act independently. Tidal asymmetry and vertical mixing determine how particles move through the water column, but their effects are modulated by density gradients that separate surface and bottom flows (6, 17, 18). Bathymetric features such as channels, shoals, and constrictions further localize retention, creating zones of accumulation that interact with both flow and particle characteristics (20). Meanwhile, particle traits, including density, size, and biofouling, define how individual plastics respond to these physical forces, influencing whether they remain trapped or are exported (10, 24).

Taken together, these factors emphasize that estuaries are complex, dynamic systems where no single process controls microplastic fate. Predicting particle retention requires considering the combined effects of flow, stratification, morphology, and particle characteristics, showcasing the need for an integrated, system-scale perspective. To advance this understanding, future research should adopt multi-scale, integrative approaches. Field measurements spanning the full water column

and multiple estuarine zones are needed to validate laboratory and modeling findings. Comparative studies of different particle types, including fibers and biofouled plastics, will clarify how particle properties interact with hydrodynamics and estuarine morphology. Numerical models should incorporate both physical and particle-specific factors to capture the relationships between mixing, stratification, bathymetry, and particle behavior. Accounting for seasonal changes in river discharge and tidal cycles will also improve predictive capacity. By focusing on these directions, the field can move beyond isolated observations to frameworks able to assess microplastic retention under varying environmental conditions and support strategies to reduce the flux of plastics to coastal ecosystems.

## ACKNOWLEDGEMENTS

I would like to thank Dr. Jaydee Edwards for her mentorship and feedback during the course of this project.

## CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

## REFERENCES

1. Lusher AL, Tirelli V, O'Connor I, Officer R. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. *Sci Rep.* 2015; 5: 14947. <https://doi.org/10.1038/srep14947>
2. Horton AA, Walton A, Spurgeon DJ, Lahive E, Svendsen C. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Sci Total Environ.* 2017; 586: 127-41. <https://doi.org/10.1016/j.scitotenv.2017.01.190>
3. Barnes DKA, Galgani F, Thompson RC, Barlaz M. Accumulation and fragmentation of plastic debris in global environments. *Phil Trans R Soc B.* 2009; 364 (1526): 1985-98. <https://doi.org/10.1098/rstb.2008.0205>
4. Lofty J, Valero D, Wilson CAME, Franca MJ, Ouro P. Microplastic and natural sediment in bed load saltation: material does not dictate the fate. *Water Res.* 2023; 243: 120329. <https://doi.org/10.1016/j.watres.2023.120329>
5. Núñez P, Castanedo S, Medina R. Role of ocean tidal asymmetry and estuarine geometry in the fate of plastic debris from ocean sources within tidal

- estuaries. *Estuar Coast Shelf Sci.* 2021; 259: 107470. <https://doi.org/10.1016/j.ecss.2021.107470>
6. Scully ME, Friedrichs CT. Sediment pumping by tidal asymmetry in a partially mixed estuary. *J Geophys Res.* 2007; 112 (C7): 2006JC003784. <https://doi.org/10.1029/2006JC003784>
  7. Burchard H, Schuttelaars HM, Ralston DK. Sediment Trapping in Estuaries. *Annu Rev Mar Sci.* 2018; 10 (1): 371-95. <https://doi.org/10.1146/annurev-marine-010816-060535>
  8. Bo T, Ralston DK, Geyer WR, McWilliams JC. On the role of small estuaries in retaining buoyant particles. *Proc Natl Acad Sci USA.* 2024; 121 (35): e2401498121. <https://doi.org/10.1073/pnas.2401498121>
  9. Teng L, Cheng H, Zhang E, Wang Y. Lateral Variation of Tidal Mixing Asymmetry and Its Impact on the Longitudinal Sediment Transport in Turbidity Maximum Zone of Salt Wedge Estuary. *JMSE.* 2022; 10 (7): 907. <https://doi.org/10.3390/jmse10070907>
  10. Li G, Chen Z, Bowen M, Coco G. Transport and retention of sinking microplastics in a well-mixed estuary. *Mar Pollut Bull.* 2024; 203: 116417. <https://doi.org/10.1016/j.marpolbul.2024.116417>
  11. Wang H, Jia Y, Ji C, Jiang W, Bian C. Internal tide-induced turbulent mixing and suspended sediment transport at the bottom boundary layer of the South China Sea slope. *J Mar Syst.* 2022; 230: 103723. <https://doi.org/10.1016/j.jmarsys.2022.103723>
  12. Kukulka T, Proskurowski G, Morét-Ferguson S, Meyer DW, Law KL. The effect of wind mixing on the vertical distribution of buoyant plastic debris. *Geophys Res Lett.* 2012; 39 (7): 2012GL051116. <https://doi.org/10.1029/2012GL051116>
  13. Kindler K, Khalili A, Stocker R. Diffusion-limited retention of porous particles at density interfaces. *Proc Natl Acad Sci USA.* 2010; 107 (51): 22163-8. <https://doi.org/10.1073/pnas.1012319108>
  14. Pritchard DW. Estuarine Hydrography. In: *Advances in Geophysics.* Elsevier; 1952; p. 243-80. [https://doi.org/10.1016/S0065-2687\(08\)60208-3](https://doi.org/10.1016/S0065-2687(08)60208-3)
  15. Seo HJ, Cho M, Yoon HD. Data-Driven Analysis of Stratified Flow Effect on Suspended Sediment Concentration in an Estuary. *JMSE.* 2020; 8 (8): 606. <https://doi.org/10.3390/jmse8080606>
  16. Geyer WR. The Importance of Suppression of Turbulence by Stratification on the Estuarine Turbidity Maximum. *Estuaries.* 1993; 16 (1): 113. <https://doi.org/10.2307/1352769>
  17. Hordoir R, Skagseth Ø, Ingvaldsen RB, Sandø AB, et al. Changes in Arctic Stratification and Mixed Layer Depth Cycle: A Modeling Analysis. *JGR Oceans.* 2022; 127 (1): e2021JC017270. <https://doi.org/10.1029/2021JC017270>
  18. Li L, He Z, Xia Y, Dou X. Dynamics of sediment transport and stratification in Changjiang River Estuary, China. *Estuar Coast Shelf Sci.* 2018; 213: 1-17. <https://doi.org/10.1016/j.ecss.2018.08.002>
  19. Ganju NK, Schoellhamer DH. Chapter 24 Lateral variability of the estuarine turbidity maximum in a tidal strait. In: *Proceedings in Marine Science.* Elsevier; 2008; p. 339-55. [https://doi.org/10.1016/S1568-2692\(08\)80026-5](https://doi.org/10.1016/S1568-2692(08)80026-5)
  20. Ralston DK, Geyer WR, Warner JC. Bathymetric controls on sediment transport in the Hudson River estuary: Lateral asymmetry and frontal trapping. *J Geophys Res.* 2012; 117 (C10): 2012JC008124. <https://doi.org/10.1029/2012JC008124>
  21. Huijts KMH, Schuttelaars HM, De Swart HE, Valle-Levinson A. Lateral entrapment of sediment in tidal estuaries: An idealized model study. *J Geophys Res.* 2006; 111 (C12): 2006JC003615. <https://doi.org/10.1029/2006JC003615>
  22. Jiang J, He L, Zheng S, Liu J, Gong L. A review of microplastic transport in coastal zones. *Mar Environ Res.* 2024; 196: 106397. <https://doi.org/10.1016/j.marenvres.2024.106397>
  23. Huang Y, Yang Z, Wang T, Liu J, Sun N, Duan Z, et al. Modeling the microplastic distribution along the Delaware River Estuary: Accumulation patterns and hydrodynamic influences. *Mar Pollut Bull.* 2025; 217: 118074. <https://doi.org/10.1016/j.marpolbul.2025.118074>
  24. Leiser R, Wu GM, Neu TR, Wendt-Potthoff K. Biofouling, metal sorption and aggregation are related to sinking of microplastics in a stratified reservoir. *Water Res.* 2020; 176: 115748. <https://doi.org/10.1016/j.watres.2020.115748>
  25. Malli A, Corella-Puertas E, Hajjar C, Boulay AM. Transport mechanisms and fate of microplastics in estuarine compartments: A review. *Mar Pollut Bull.* 2022; 177: 113553. <https://doi.org/10.1016/j.marpolbul.2022.113553>