Shifts in riverine POC sources reduce terrestrial OC burial in the Changjiang subaqueous ~~Changjiang Delta~~delta

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Abstract. Global riverine particulate organic carbon (POC) fluxes have declined worldwide due to dam-induced reductions in sediment load. However, how the composition of riverine POC has evolved in response to declining sediment supply, and how such shifts influence OC burial in subaqueous deltaic systems remain unclear. Here, we collected suspended particulate matter (SPM) from the Changjiang Estuary ~~during~~ in ~~the~~ summer and winter ~~of~~ 2025 to analyze N/C molar ratios and $\delta^{13}C$ values. These data were integrated with a four-decade (1980–2021) dataset comprising POC proxies (N/C molar ratios, $\delta^{13}C$~~,~~ and $\Delta^{14}C$) for SPM in the estuary and surface sediments from the Changjiang subaqueous ~~Changjiang Delta~~delta. Our results reveal a temporal increase in N/C molar ratios and a decrease in $\delta^{13}C$ values in riverine SPM. Based on a Bayesian end-member mixing model, we attribute these trends to an increasing proportion of POC derived from freshwater algae and a decreasing proportion of POC originating from soil/bedrock erosion. This temporal ~~increment~~ increase in river-delivered labile algae POC drove a ~~1.5-fold~~ decrease in OC preservation efficiency in the Changjiang subaqueous ~~Changjiang D~~delta from 15.1% (before 2003) to 10.7% (after 2003), resulting in a ~~more~~ pronounced reduction in deltaic OC burial. Consequently, the amount of OC retained in sediments decreased by approximately 50%, from ~~0.68×10^{5}~~68 kt/month in 2001 to an average of ~~0.34×10^{5}~~34 kt/month during the flood seasons of 2011–2020. Our findings emphasize that the shifts in riverine OC sources, not merely the decline in total OC flux, may exert great effects on OC burial in deltaic systems globally.

1 Introduction

Rivers deliver annually a large amount of (480 Mt/yr) terrestrial organic carbon (OC) into the ocean, and thus plays a key role in land-ocean carbon cycling and further climate change (Galy et al., 2015; Regnier et al., 2022; Liu et al., 2024). Particulate OC (POC)~~, generally identified as organic particles with size larger than 0.7 μm,~~ is an important component of riverine OC, accounting for approximately 180 Mt C budgets input into the ocean each year (Liu et al., 2024). In recent decades, however, the riverine sediment loads have decreased sharply worldwide due to anthropogenic activities including river damming, land

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use change and water and soil conservation policies (Dethier et al., 2022), ~~which~~ exert~~s~~ing a substantial influence on riverine POC budgets and the broader global OC cycles (Maavara et al., 2017; Ke et al., 2022).

Delta~~s~~ and their~~its~~ adjacent inner shel~~ves~~f, account for~~constituting~~ less than ~~<~~ 10% of the ~~entire~~ global ocean area, but contribut~~e~~ing more than~~>~~ 90% ~~to the~~of overall OC ~~preservation~~ burial in the oceans ~~globally~~, making them disproportionally important hotspots for oceanic OC preservation~~act a disproportional hotspot in oceanic OC burial~~ (Hedges and Keil, 1995; Muller-Karger et al., 2005; Hage et al., 2022). As the channels connecting terrestrial and marine realms, sediments in these regions are subjected to complex marine hydrodynamic settings during seaward transport, resulting in OC exchange between sediment-water interface and ultimately OC burial (Blair and Aller, 2012; Bauer et al., 2013). Given that a substantial fraction of riverine POC is ~~ultimately~~ deposited in deltaic sediments, the marked decline in POC flux would be expected to have profound implications for OC burial in these coastal depocenters. In two largest rivers of China, the Changjiang River and the Yellow River, the POC fluxes decreased evidently from 13.4 and 7.7 Tg/yr in 1950s to 2.9 and 0.4 Tg/yr in 2016, respectively (Liu et al., 2020). In mainstem of the Red River in Vietnam, the POC fluxes decreased evidently from 0.68 Tg/yr in 1960s to 0.05 Tg/yr in 2016 (Le et al., 2018)~~, as the clearly temporal decline of sediment loads in the river (Dang et al., 2010)~~.

Riverine POC originates from multiple sources that ~~exhibit distinct degrees~~span a continuum of lability under varying physicochemical conditions (Hilton et al., 2024). For instance, petrogenic OC, primarily supplied by bedrock and soil erosion in the upstream watershed, is relatively stable during riverine transport due to its strong organo-mineral protection. Nevertheless, this stability can be disrupted in estuarine environments, where intense shear stress destabilizes organo-mineral associations and enhances degradation (Sun et al., 2022; Sun et al., 2024). In contrast, algal-derived OC, mainly produced by aquatic plankton, is highly labile and readily decomposed in the water column through biological processes owing to its enrichment in proteins, carbohydrates~~,~~ and lipids with high bioavailability (Wang et al., 2024). Vascular plant–derived POC, primarily composed of ~~dominated by debris from~~ C3 plants debris ~~in~~ from the watershed, is generally resistant to degradation during downstream transport; as a result, it can be ~~conveyed over~~transported over long distances and ultimately deposited and preserved within proximal deltaic sediments (Rathburn et al., 2017; Sun et al., 2021). These source-specific POC components respond sensitively to variations in sediment flux, and their relative contributions exert a critical influence on OC transport and burial along the river–estuary–shelf continuum. Given the substantial shifts in riverine sediment budgets, as well as the consequent changes in both the magnitude and composition of POC delivery, the fluxes of OC burial in deltaic areas may change profoundly and necessitates a systematic re-evaluation.

The Changjiang River offers an ideal natural laboratory to address this knowledge gap. Due to the construction of upstream dams since 1980s, the Changjiang River had experienced sustained reduction in sediment load over time (Fig. 1f). Sediments delivered by the river are predominantly deposited in the Changjiang subaqueous ~~Changjiang D~~delta, while this depocenter has experienced extensive seabed erosion in response to the reduced fluvial sediment supply (Luan et al., 2016). Previous work has shown that POC burial in the subaqueous delta has decreased markedly, primarily driven by the sharp reductions in transport flux and deposition rate of OC-bearing sediments (Zhao et al., 2021a). However, how terrestrial POC components shift in response to declining sediment supply and their impact on deltaic OC burial have not yet been clearly elucidated. By integrating a multi-decadal dataset of OC-related characteristics (C/N, $\delta^{13}C$ and $\Delta^{14}C$) from suspended sediments in the Changjiang Estuary and surface sediments in the Changjiang subaqueous ~~Changjiang D~~delta with a Bayesian end-member mixing model, our study attempts to clarify: (i) temporal changes of different sources of terrestrial OC input into the ocean; and (ii) how these variations affect OC burial in the Changjiang subaqueous ~~Changjiang D~~ delta.

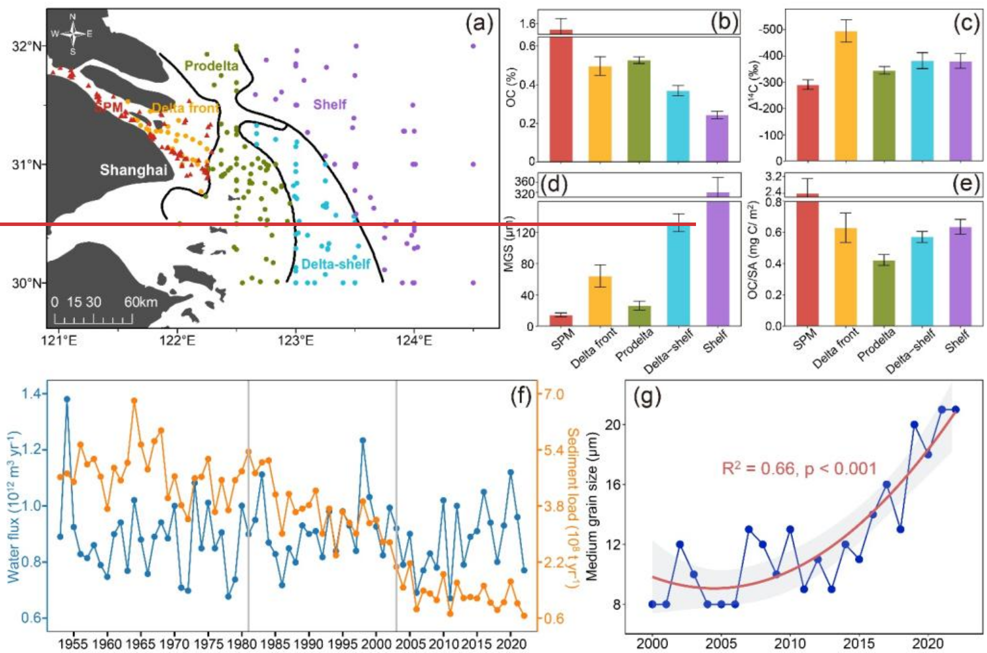
2 Material and methods

2.1 Study area

Changjiang River, with a length of 6300 km and a watershed area of 1.8×10^6 km^2, is the largest river in East Asia (Fig. S1). Prior to the construction of dams, the river annually delivered approximately 472 Mt of sediment and 900 km^3 of freshwater to the East China Sea (Zhao et al., 2021a). These fluxes were predominantly concentrated during the flood season (June–October), accounting for over 70% of the annual water discharge and more than 87% of the sediment load, in contrast to the dry season (November–May) (China River Sediment Bulletin, 2000–2022)~~CWRC, 1953–2022~~). Historically, the estimated OC budgets export to the estuary ranged from 0.86 to 13 Mt yr^{-1}, of which approximate 50% was POC (Milliman et al., 1985; Wang et al., 2012). However, the sediment flux and its related POC flux declined continuously since about 1981 due to sediment retention by upstream dam operation (Fig. 1f). Two sharp reductions of sediment flux were observed in 1981 and 2003, respectively, corresponding to the commissioning year of Gezhouba Dam and Three Gorges Dam that constructed in main stream of the Changjiang River (Fig. S1; Table S1). Given the limited dataset prior to the operation of the Gezhouba Dam in 1981~~0~~, the commissioning of the Three Gorges Dam (2003) was used as a temporal breakpoint to examine changes in the characteristics of river-delivered POC and deltaic OC associated with the sharp reduction in sediment flux.

The East China Sea is affected by a complex circulation system driven by the East Asian monsoon and Kuroshio–shelf interactions (Fig. S2). Major currents in this region include the Changjiang Diluted Water, Taiwan Warm Current and Kuroshio Current. These currents regulate regional water-mass exchange and the along-shelf transport of Changjiang-derived materials. Within this circulation setting, the Changjiang subaqueous delta forms a major depositional region at the land–sea interface and provides an important area for investigating sedimentary OC burial. More than 90% of the ~~riverine~~ sediments deposited in the Changjiang subaqueous ~~Changjiang D~~delta are derived from the Changjiang River; in comparison, the contributions from other rivers, including Yellow River, Qiantang River and Taiwanese rivers, are relatively small that can be basically ignored (Liu et al., 2007; Van der Voort et al., 2018). Because of the accumulation of a large amount of POC, the Changjiang subaqueous ~~Changjiang D~~ delta ~~was~~ ~~is generally~~ widely ~~considered~~ recognized as an important ~~critical area for~~ OC sink (Zhao et al., 2021a; Shi et al., 2024; Ran and Wang, 2025). The combined influence of ~~Under the strong hydrodynamic interactions among~~ river discharge~~, tides,~~ and ~~coastal currents~~complex regional shelf circulation (~~e.g., the Zhejiang–Fujian and Yellow Sea Coastal Currents~~Fig. S2)~~,~~ leads to spatially heterogeneous sediment deposition and distinct grain-size distributions across the ~~sediments with distinct grain size deposited in different nearshore regions of the Changjiang Estuary~~Changjiang subaqueous delta.

Based on the characteristics of ~~these~~ accumulated sediments, the Changjiang subaqueous ~~Changjiang Delta~~ delta can be subdivided into four sedimentary ~~units~~ facies~~(Chen et al., 1991)~~: the Delta front, the Prodelta, the transition zone from delta to continental shelf (Delta-s~~S~~helf), and the continental shelf (Shelf) (Fig. 1a; Chen et al., 1991). The Delta front, located at water depths shallower than 12 m, lies above the wave base and has a gentle slope. It is dominated by silty sediments and is subject to strong river–tidal dynamics, resulting in relatively low sedimentation rates (Jia et al., 2018). The Prodelta, at water depths of 12–50 m, shows an offshore transition from silt to silty clay and is characterized by weaker hydrodynamic conditions and higher sediment accumulation rates (Wei et al., 2007). The Delta–shelf transition zone, at water depths of 50–60 m, contains mixed and poorly sorted sediments with abundant shell debris, indicating sediment reworking by storms and bottom currents, and thus relatively low and spatially heterogeneous sediment accumulation (Chen et al., 2000). The Shelf facies, located farther seaward at water depths greater than 60 m, is dominated by relict shelf sands and is more strongly influenced by regional shelf circulation, representing a shallow-marine depositional environment (Chen et al., 2000; Zhan et al., 2020). These contrasts in hydrodynamic conditions, sediment sources, grain-size composition, and sediment accumulation rates provide the sedimentological basis for comparing OC burial patterns across different depositional environments.


(a)
N
W
E
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32°N
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121°E
122°E
123°E
124°E
Prodelta
Shelf
SPM
Delta front
Shanghai
Delta-shelf
0 15 30 60km
(b)
OC (%)
(c)
Δ14C (‰)
(d)
MGS (μm)
(e)
OC/SA (mg C/ m2)
SPM
Delta front
Prodelta
Delta-shelf
Shelf
(f)
Water flux (10^12 m^3 yr^-1)
Sediment load (10^8 t yr^-1)
(g)
Medium grain size (μm)
R2 = 0.66, p < 0.001

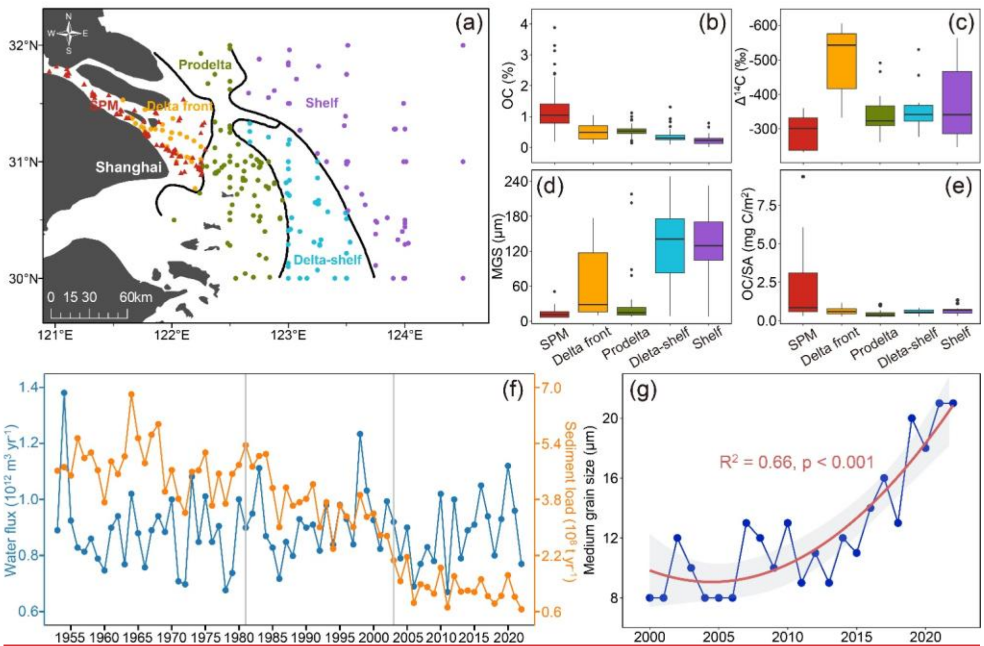

Figure 1 Sampling sites of suspended particulate matters (SPM) and surface sediment in Changjiang Estuary and its adjacent areas, including both field-collected samples and literature-compiled data (a). Differences in parameters between~~Characteristics of sediment in~~ riverine SPM and deltatic sediments, including organic carbon (OC) ~~content~~ concentrations (b), $\Delta^{14}C$ (c), medium grain size (MGS) (d) and ratios between OC ~~content~~ concentrations and specific surface area (OC/SA) (e). Variations of annual mean water flux and sediment load of the Changjiang River from 1953 to 2022 (f). Changes of annual MGS of the sediment delivered by the Changjiang River from 2000 to 2022 (g). Four sedimentary ~~units~~ facies (Delta front, Prodelta, Delta-shelf and Shelf) of the Changjiang subaqueous ~~Changjiang Delta~~ delta in panel (a) are classified according to Chen et al. (1991) and delineated by black lines. In panels (b-e), the horizontal line inside each box represents the median, and the lower and upper edges of the box indicate the first and third quartiles, respectively. The box height denotes the interquartile range (IQR), and the whiskers extend to the most extreme data points within 1.5 × IQR of the lower and upper quartiles. The two grey vertical lines in panel (f) correspond to the construction of the Gezhouba Dam in 1981 and the Three Gorges Dam in 2003, respectively, on the mainstream of the Changjiang River. Data of riverine water flux, sediment load and MGS in Datong Gauge Station are applied to represent characteristics of water and sediment input into the East China Sea~~, which are obtained from annual China River Sediment Bulletin~~ (based on Zhao et al. (2021a) and China River Sediment Bulletin (2000–2022)~~CWRC, 1953–2022~~). The fitted line in panel (g) represents a quadratic fit, and the grey shaded area indicates the 95% confidence interval.

2.2 Samples collection and ~~analysis~~data compilation

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The suspended particulate matter (SPM) samples from the Changjiang Estuary were collected during winter (March) and summer (July) cruises in 2025 aboard the R/V Runjiang I. At each sampling site, surface seawater was collected using a Seabird® SBE 55 water sampler and subsequently filtered through pre-combusted (450 °C, 5 h) 0.7 μm glass fiber membranes

(47 mm diameter, Whatman GF/F) and pre-weighed 0.7 µm acetate cellulose membranes, respectively. In total, 20 SPM samples were collected. To determine the OC-related ~~characteristics~~ parameters (C/N, $\delta^{13}C$), the particle-laden glass fiber membranes were acidified with 4 mol/L HCl for 24 h to remove inorganic carbon completely (Leithold et al., 2013) prior to analysis using an Elemental Analyzer (Elementar Analysen Systeme GmbH, Germany) and an Isotope-Ratio Mass Spectrometer (IRMS, IsoPrime100, UK). Total suspended matter (TSM) concentrations were obtained gravimetrically by calculating the weight difference of the acetate cellulose membranes before and after freeze-drying.

~~2.3 Data compilation~~

A dataset of OC-related parameters (N/C molar ratio, $\delta^{13}C$ and $\Delta^{14}C$) and sediment characteristics (medium grain size (MGS); specific surface area (SA)) in SPM in Changjiang Estuary and surface sediments in the Changjiang subaqueous ~~Changjiang Delta~~ delta from 1980 to 2021 was compiled. The dataset was comprehensively incorporated the available sources (data was shared or can be extracted from figures and tables) from published articles. To better approximate a terrestrially dominated POC source, we refined the SPM dataset by selecting surface samples collected mainly from nearshore, low-salinity estuarine waters, which are generally more strongly influenced by riverine inputs than by marine production (Yao et al., 2024). ~~To represent a purely terrestrial OC source, the SPM data was refined by selecting surface samples with salinity levels of sampling sites below approximately 20 (Yao et al., 2024).~~ Together with the SPM samples collected during our field work in winter and summer 2025, a total of 321 individual samples ~~In total, 301 individual data samples~~ were incorporated in the dataset, including ~~64~~ 84 SPM and 237 surface sediments (Fig. 1a). ~~Dataset of annual water and sediment flux from 1953 to 2022, the monthly water and sediment flux (June and July) from 2001 to 2020, as well as the MGS of the SPM from 2000 to 2022 was obtained from the Hydrological Statistical Yearbook of the Ministry of Water Resources of the People's Republic of China (CWRC, 1953–2022) based on the continuous observation in Datong gauging station (30°6′N, 117°7′E).~~ Details of the data processing are presented in the Supplementary Material.

2.~~4~~ 3 Sources of OC in SPM and surface sediment

The Bayesian end-member mixing model, implemented in R Studio (version 4.2.3) based on the "*rjags*" package, was run with 10^7 iterations, using a burn-in of 10~~,~~000 steps, and a data thinning of 100 according to (Andersson et al., 2015). By using N/C molar ratio and $\delta^{13}C$ values, the relative contributions of three sources of POC in SPM were separated, targeting petrogenic ($f_{Petrogenic}$), C3 plant (f_{Plant}) and algae sources (f_{Algae}), based on the following formulas:

$$(f_{Petrogenic} \times N/C_{Petrogenic}) + (f_{Plant} \times N/C_{Plant}) + (f_{Algae} \times N/C_{Algae}) = N/C \quad (1)$$

$$(f_{Petrogenic} \times \delta^{13}C_{Petrogenic}) + (f_{Plant} \times \delta^{13}C_{Plant}) + (f_{Algae} \times \delta^{13}C_{Algae}) = \delta^{13}C \quad (2)$$

$$f_{Petrogenic} + f_{Plant} + f_{Algae} = 1 \quad (3)$$

where f represents the proportion of a specific terrestrial source of POC in SPM. Selection of end-member values is presented in Table S2.

Because of the nonnegligible marine OC generated in nearshore regions off the Changjiang Estuary, the ~~sedimentary~~ OC in surface sediment in the Changjiang subaqueous ~~Changjiang Delta~~ delta is divided into terrestrial and marine sources according to the following formulas:

$$(f_{Terrestrial} \times \delta^{13}C_{Terrestrial}) + (f_{Marine} \times \delta^{13}C_{Marine}) = \delta^{13}C \quad (4)$$

$$f_{Terrestrial} + f_{Marine} = 1 \quad (5)$$

where f represents the proportion of OC source, and the end-member values of $\delta^{13}C$ are -25.6‰ and -20.0‰ for terrestrial and marine source, respectively (Chen et al., 2021).

2.~~5~~ 4 OC burial efficiency and OC preservation efficiency

The OC burial efficiency in surface sediments in the Changjiang subaqueous ~~Changjiang Delta~~ delta was estimated according to Keil et al. (1997) through the following formula:

$$OC\ burial\ efficiency\ (\%) = \frac{OC\ loading_{\ Surface\ sediment}}{OC\ loading_{\ SPM}} \times 100\% \quad (6)$$

where the $OC\ loading_{\ Surface\ sediment}$ represents the loading of terrestrial OC (OC/SA× terrestrial OC proportion) in surface sediment, and the $OC\ loading_{\ SPM}$ denotes the OC/SA in SPM.

Note that $OC\ loading_{\ SPM}$ is used here to approximate the OC loading of terrestrially dominated SPM normalized to its specific surface area. Although this approximation may lead to an underestimation of OC burial efficiency because marine-derived OC was not explicitly separated from bulk OC, the studied estuarine SPM samples were collected from the low-salinity mixing zone, where riverine particles and terrestrial OC inputs generally dominate the suspended particle pool and the influence of marine primary production is expected to be limited (Yao et al., 2024). Thus, the contribution of marine-derived OC is likely minor relative to the terrestrial component, and the use of OC loading SPM as an approximation of terrestrial OC loading is considered reasonable.

Besides the calculation of OC burial efficiency, we also estimated the preservation of terrestrial OC during sediment transport by comparing differences between the terrestrial OC concentrations~~content~~ (expressed as wt% of dry sediment) in surface sediments and riverine SPM in terms of Blair and Aller (2012). To distinguish this metric from burial efficiency, it is defined as preservation efficiency in our study. The preservation efficiencies of terrestrial OC in different sedimentary ~~units~~ facies of the Changjiang subaqueous ~~Changjiang Delta~~ delta are calculated through the following formula:

$$OC\ preservation\ efficiency\ (\%) = \frac{OC_{\ Surface\ sediment}}{OC_{\ SPM}} \times 100\% \quad (7)$$

where the $OC_{\ Surface\ sediment}$ represents the ~~content of~~ terrestrial OC concentrations ~~-~~ in surface sediment, and the $OC_{\ SPM}$ denotes the OC ~~content~~ concentrations in SPM.

Based on the assessed OC burial and preservation efficiencies at different sampling sites, we calculated the overall OC burial and preservation efficiencies across the entire subaqueous Changjiang Delta. Using the estimated OC preservation efficiency, we further quantified the net preservation flux of terrestrial OC delivered by the Changjiang River. Details of the data calculations are provided in the Supplementary Material.

2.6 5 Statistical analyses

Regression analysis, conducting by R Studio (version 4.2.3), is utilized to estimate the temporal trend of hydrological and sediment characteristics, OC-related parameters (N/C molar ratio, $\delta^{13}C$), proportion of different sources of terrestrial POC in SPM, as well as riverine POC flux and amounts of OC preserved in the Changjiang subaqueous Changjiang Deltadelta. Relationships between C/N and $\delta^{13}C$ were exhibited to identify different sources of OC in SPM and surface sediments. Kriging interpolation, by using ArcMap 10.8, was applied to present horizontal patterns of OC preservation efficiency in the Changjiang subaqueous Changjiang Deltadelta. Factors controlling OC loss and retention during sediment transport are proved by establishing relationships between OC loading (OC/SA), OC characteristics (C/N, $\delta^{13}C$ and $\Delta^{14}C$) and sediment parameters (MGS, SA) in SPM and surface sediment through scatter plot and linear regression analysis.

3 Results

3.1 Temporal shifts in riverine SPM and spatial heterogeneity in deltaic sediments

Since 2000, the grain size of SPM delivered to the East China Sea has progressively ($p < 0.001$) coarsened (Fig. 1g), indicating that anthropogenic activities, particularly dam construction such as Three Gorges Dam in 2003 (Table S1), have exerted a substantial influence on the characteristics of river-delivered materials. The operation of the Three Gorges Dam has also altered the composition of riverine POC, as reflected by C/N ratios and $\delta^{13}C$ signatures that capture a clear transition in POC sources, from mainly petrogenic to algal OC over time (Fig. S2).

In addition, marked spatial heterogeneity in OC-related indices and sediment characteristics was observed across the four sedimentary units (Fig.1). OC content was substantially higher in nearshore zones than in offshore areas (Fig. 1b), consistent with the fining trend in sediment grain size shoreward (Fig. 1d). While when considering OC loading (OC/SA), the values were comparable across three sedimentary units, except for notably lower levels in the Prodelta (Fig. 1e). For $\Delta^{14}C$, the lowest value was recorded in Delta front, whereas the other units exhibited little differences (Fig. 1c).

3.2 1 Temporal variations in grain size ofand OC characteristics in of riverine SPM

Since 2000, the grain size of Changjiang-derived SPM delivered to the East China Sea has progressively coarsened ($p < 0.001$; Fig. 1g). Concurrently, C/N ratios and $\delta^{13}C$ values exhibited systematic temporal changes, with riverine POC composition shifting from a higher petrogenic OC contribution toward a greater algal OC contribution (Fig. S3).

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The N/C molar ratio in surface SPM collected within the Changjiang Estuary increased significantly ($p < 0.001$) from 1980 to 2025, with the value ~~rise approximately 2.5-fold~~increasing from 0.07 in 1980 to 0.17 in 2025 (Fig. 2a). In comparison, the $\delta^{13}C$ values decreased evidently ($p < 0.01$) during the same period (Fig. 2c), with the value ranged between -23.5‰ to -28.0‰ (Table S3). Between flood and dry seasons, the N/C and $\delta^{13}C$ exhibited limited differences ($p > 0.05$) (Fig. 2b, d).

Based on the Bayesian End-member Mixing model, the riverine POC in SPM were separated into three terrestrial sources (algae, petrogenic and C3 plant). Temporally, the proportion of algae OC increased significantly ($p < 0.01$), rising ~~approximately 2.6-fold~~ from 16% in 1980 to 42% in 2025. In contrast, the proportion of petrogenic OC showed a marked decline ($p < 0.01$), decreasing ~~roughly 2.3-fold~~ from 63% in 1980 to 27% in 2025 (Fig. 2e). The contribution of C3 plant OC exhibited limited temporal variation ($p > 0.05$), ranging between 22% and 35% over the study period (Fig. 2e).

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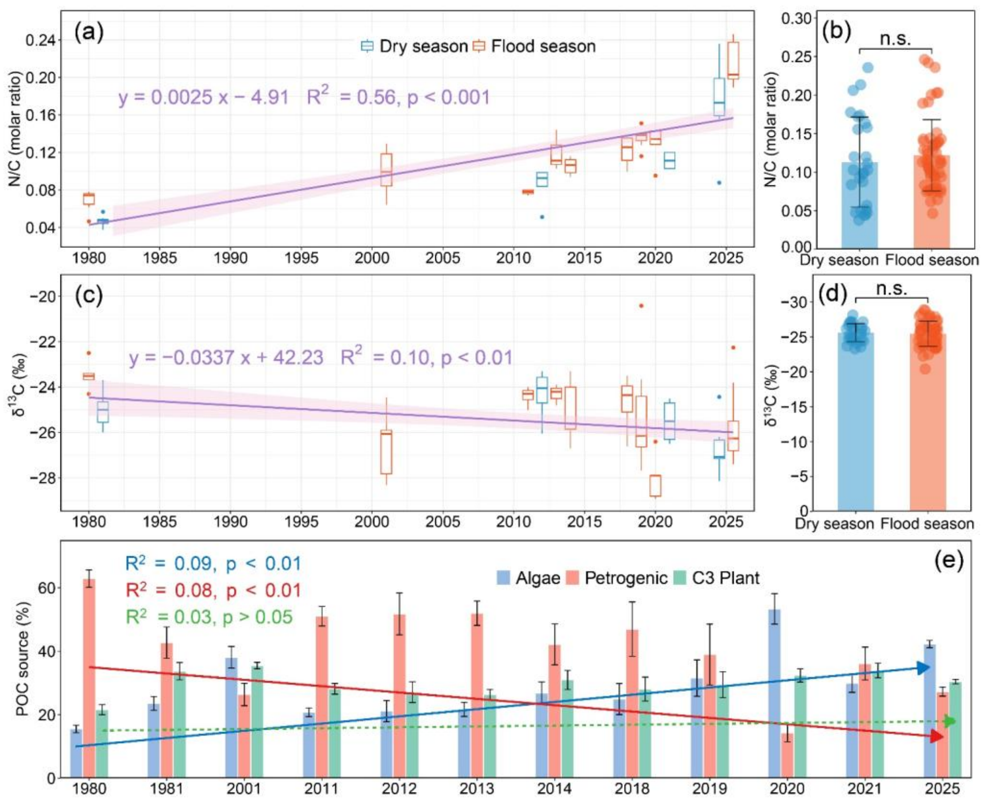

Figure 2 Temporal variations of N/C molar ratios (a) and δ^{13}C values (c) in suspended particulate matter (SPM) collected in surface water in the Changjiang Estuary from 1980 to 2025~~, and the~~. ~~D~~differences of N/C molar ratios (b) and δ^{13}C values (d) between dry and flood seasons. Temporal trends of proportions of particulate organic carbon (POC) derived from different terrestrial sources (algae, petrogenic and C3 plant sources) estimated through a Bayesian End-member Mixing approach from 1980 to 2025 (e). Solid lines represent significant ($p < 0.05$) linear associations, and the light purple areas around the line indicate 95% confidence interval. The n.s. indicates insignificant ($p > 0.05$) differences.

3.2~~3~~ Spatial heterogeneity and temporal ~~C~~changes ~~of~~ in OC characteristics ~~in surface sediment~~among sedimentary facies

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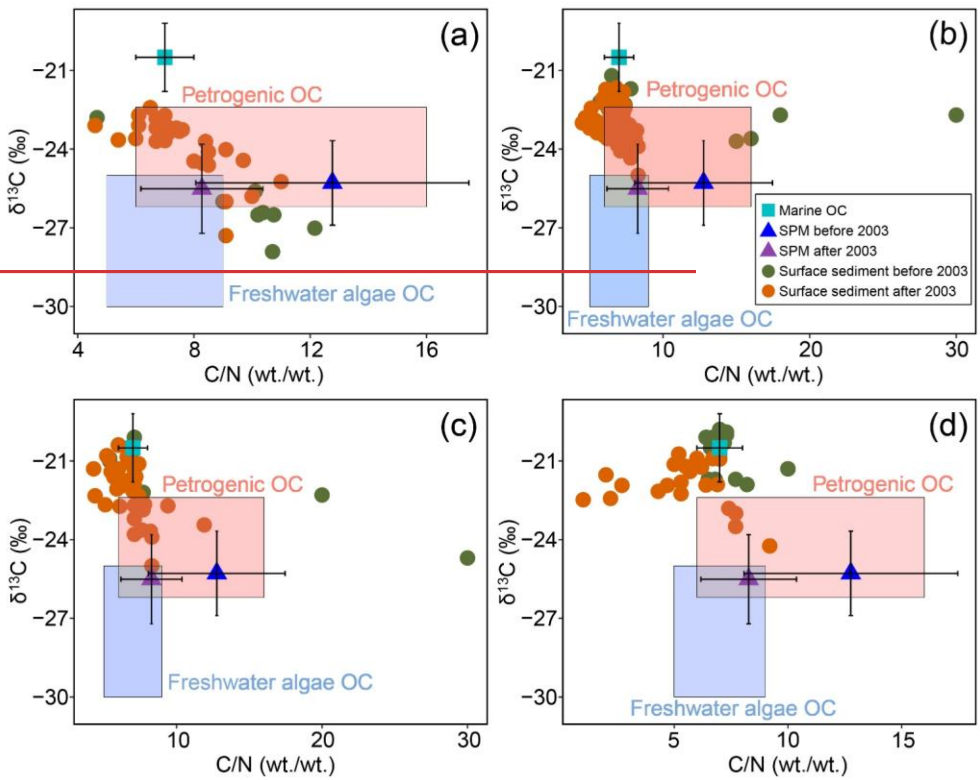
Marked spatial heterogeneity in OC-related indices and sediment properties was observed across the four sedimentary facies. OC concentrations were substantially higher in nearshore zones than in offshore areas (Fig. 1b), corresponding to the seaward coarsening of sediment grain size (Fig. 1d). In contrast, OC loading (OC/SA) was generally comparable among sedimentary facies, except for notably lower values in the Prodelta (Fig. 1e). For Δ^{14}C, the lowest values were recorded in the Delta Front, whereas the other facies exhibited little differences (Fig. 1c).

In the Delta front, the values of δ^{13}C and C/N in surface sediment ~~were~~ increased and decreased over time, respectively (Fig. 3a). Surface sediments collected after 2003 exhibit δ^{13}C and C/N values that predominantly plot within the petrogenic domain, aligning along a mixing line between marine and riverine OC end-members. In contrast, samples collected prior to 2003 display that the δ^{13}C and C/N fall outside the fields defined for either petrogenic or freshwater algal sources, lying outside of a simple mixing between two end-members of marine and riverine OC ~~(Fig. 3a)~~. In the Prodelta, the δ^{13}C and C/N ratios in surface sediments exhibited minor temporal variability (Fig. 3b). A slight depletion in δ^{13}C was observed in pre-2003 samples compared to those after 2003. Most data points plot within the petrogenic domain and align along a mixing line between marine and riverine OC end-members ~~(Fig. 3b)~~. By comparison, ~~the values of~~ δ^{13}C and C/N values in both Delta-shelf and Shelf displayed limited temporal change (Fig. 3c, d). ~~They~~ These values ~~are~~were consistently closer to the marine OC end-member (δ^{13}C = -20.5‰, C/N = 7), ~~and~~with only partial~~ly~~ overlap with the petrogenic component, and fell~~falling~~ within a mixing zone ~~of~~ between marine and riverine OC ~~(Fig. 3c, d)~~.


(a)
(b)
(c)
(d)
Petrogenic OC
Freshwater algae OC
δ13C (‰)
C/N (wt./wt.)
Marine OC
SPM before 2003
SPM after 2003
Surface sediment before 2003
Surface sediment after 2003

255

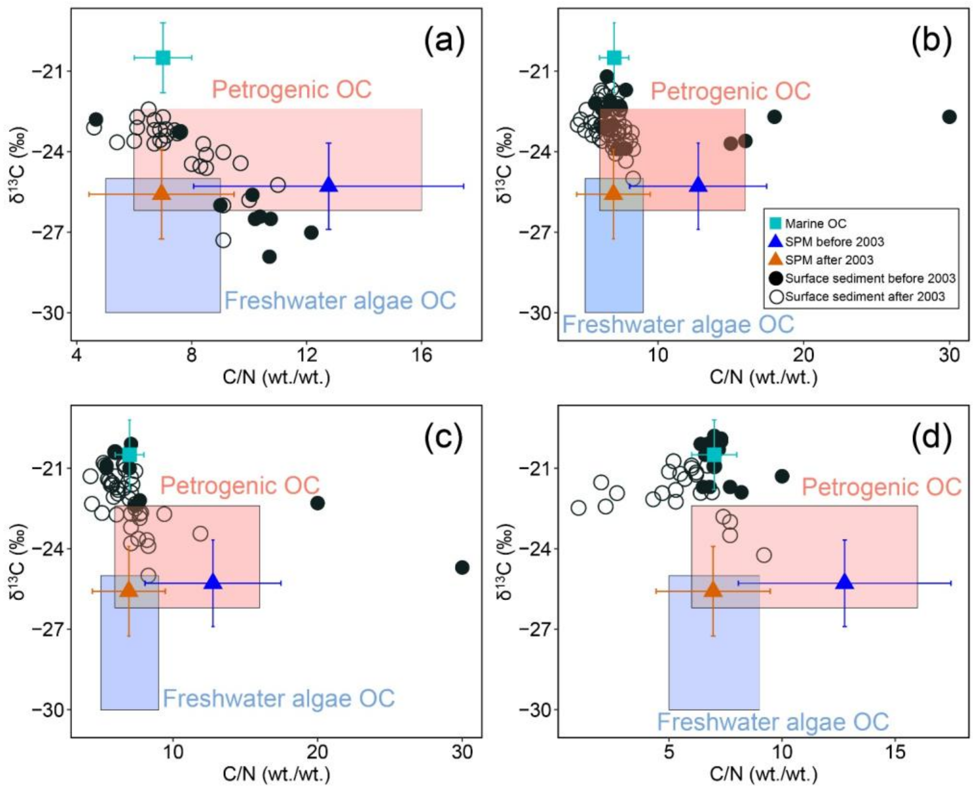


Figure 3 Relationships between δ^{13}C and C/N in surface sediments in the Delta front (a), Prodelta (b), Delta-shelf (c) and Shelf (d) prior to before and after 2003. Light red and blue areas represent ranges of δ^{13}C and C/N corresponding to terrestrial organic carbon (OC) derived from petrogenic and freshwater algae OC sources, respectively, in terms of Lamb et al. (2006) and Menges et al. (2020). The marine OC end-member of δ^{13}C is from -19.2‰ to -21.8‰ and of C/N is 6–8 (Xing et al., 2011; Bao et al., 2018).

3.4 3 OC burial efficiency and OC preservation efficiency

Terrestrial OC burial efficiency in the Changjiang subaqueous Changjiang Delta delta is 12.6%, with the range from 2.3 to 43.3% (Fig. S4). Higher OC burial efficiencies efficiency were was observed in the Delta front (21.3%), which were significantly higher ($p < 0.05$) than that in the Prodelta (9.8%), Delta-shelf (9.6%) and Shelf (9.7%) (Fig. S4a). The OC burial efficiency is positively and closely ($p < 0.001$) related to OC preservation efficiency (Fig. S4b). The OC preservation efficiency in the Changjiang subaqueous delta is 11.2%, with the range from 0.4 to 39.2% (Fig. 4a). Higher OC preservation efficiencies

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efficiency ~~were~~ was detected in the Delta front (16.8%) and Prodelta (15.7%) regions when compared with the Delta-shelf (7.5%) and Shelf (4.7%) (Fig. 4b).

Temporally, the OC preservation efficiency decreased ~~by approximately 1.5-fold,~~ from 15.1% before 2003 to 10.7% after 2003 (Fig. 4c). During flood seasons, based on these estimated preservation efficiencies, the amounts of OC preserved in sediments decreased by about 50%, from ~~0.68 × 10^5~~68 kt/month in 2001 to an average of ~~0.34 × 10^5~~34 kt/month during 2011 to 2020 (R^2 = 0.27, $p < 0.01$). Similarly, the riverine OC flux decreased by approximately 49%, from ~~4.5 × 10^5~~450 kt/month in 2001 to an average of 230~~2.3 × 10^5~~ kt/month (R^2 = 0.28, $p < 0.01$) (Fig. 4d).

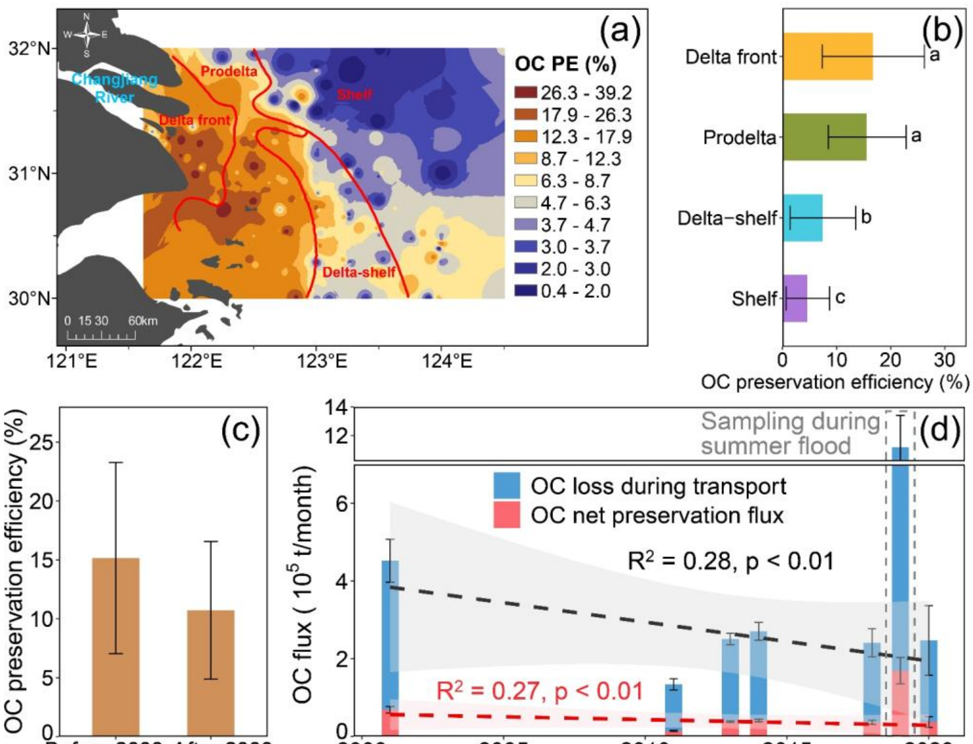

Figure 4 Distribution of organic carbon (OC) preservation ~~efficiencies~~ efficiency in the Changjiang subaqueous ~~Changjiang Delta~~delta~~, PE: preservation efficiency (%)~~ (a), and OC preservation efficiency in different sedimentary ~~units~~ facies (b). Comparison of OC preservation efficiency before and after 2003 (c). Temporal trends of the amount of OC preserved (red dashed line) in deltaic sediments and riverine OC flux (black dashed line) from 2001 to 2020, and the blue bars reflect OC loss (difference between amount of OC preservation and riverine OC flux) during sediment ~~seaward~~ transport (d). The PE indicates preservation efficiency in panel (a). Different lowercase letters in panel (b) denote statistically significant differences ($p < 0.05$) among sedimentary ~~units~~facies. In

panel (d), the high value in 2019 (gray dashed circles) primarily induced by extreme summer flood (Sun et al., 2021) was excluded from trend analysis. The dashed lines indicate linear relationships, and the light gray and red areas around the line represent 95% confidence interval.

4 Discussions

4.1 Temporal changes of riverine POC sources in the Changjiang Estuary

Since the construction and operation of mainstream dams in the upper reaches of the Changjiang River began~~beginning~~ in the 1980s, the characteristics of terrestrial POC transported to the East China Sea have changed markedly, with N/C molar ratios increasing significantly ($p < 0.001$) and $\delta^{13}C$ values decreasing significantly ($p < 0.01$) over time (Fig. 2a, c). These shifts resulted in temporally elevated proportion of POC derived from freshwater algae and declined proportion of POC originated from watershed bedrock/soil erosion (Fig. 2e). ~~Despite~~ Although previous studies ~~had~~ have revealed the increased proportion of freshwater algae source OC induced ~~from~~ by the impoundment of Three Gorges Dam ~~impoundment~~ after 2003 (Wang et al., 2021; Lyu et al., 2023; Wang et al., 2024; Ke et al., 2025), we propose~~d~~ that this shift may have initia~~t~~led ~~since~~ in the 1980s, when ~~the~~ sediment loads begin to decrease under the operation of the Gezhouba Dam ~~in~~ on the mainstem of the Changjiang River (Fig. 1f; Fig. S1; Table S1). Notably,~~e~~ the ~~higher~~ N/C molar ratio was evidently higher ~~(0.099)~~ in 2001 (0.099) ~~that was approximately 1.5-fold~~ than ~~0.068~~ in 1980 (0.068) (Fig. 2a), ~~which~~ reflecting~~ed~~ ~~that the~~an increase in the proportion of ~~algae~~ algal OC ~~increased~~ from 16% in 1980 to 38% in 2001, and ~~the proportion of petrogenic OC~~ a decrease~~d~~ in the proportion of petrogenic OC from 63% in 1980 to 26% in 2001 (Fig. 2e). These results capture, for the first time, the temporal variations in the relative contributions of different terrestrial sources of POC input into the East China Sea, highlighting the substantial influence of anthropogenic disturbances on the composition of river-borne terrestrial POC.

Despite the ~~scarcity~~ limited number of studies examining the impacts of river damming on the temporal variations of individual terrestrial OC sources along the river–ocean continuum, our findings are broadly consistent with previous studies conducted within the Changjiang River Basin. The impoundment of Three Gorges ~~Reservoir~~ Dam in 2003 significantly raised the proportion of riverine primary productivity-derived POC in the downstream ~~of the~~ Changjiang River, resulting in higher fluxes of these labile POC components entering into the East China Sea (Lyu et al., 2023). Wang et al. (2024) ~~had~~ also revealed that the proportion of autochthonous OC, ~~originating~~ originated from aquatic primary productivity, increased markedly from the Three Gorges ~~Reservoir~~ Dam to the estuary ~~in the mainstem of~~along the Changjiang ~~River~~mainstem. Changes ~~of~~ in the relative contributions of different POC sources in the Changjiang River ~~were~~ are also comparable ~~with~~ to those observed in other large rivers worldwide that have experienced intensified anthropogenic activities. ~~In the Mississippi, Colorado, Rio Grande, and Columbia Rivers, four major waterways in the United States, the construction of several dams has led to marked reductions in sediment loads. This alteration has, in turn, resulted in a notable increase in the relative contribution of plankton-derived POC in downstream waters relative to upstream areas (Kendall et al., 2001). In Yellow River, before and after the water-sediment regulation by Xiaolangdi Reservoir, the proportion of terrestrial POC derived from soils increased significantly from 56.4% to 82.0%, and the proportion of plant-originated POC declined from 43.6% to 18% (Lv et al., 2022).~~ In four major rivers in

United States—the Mississippi, Colorado, Rio Grande, and Columbia—the construction of dams has substantially increased the relative contribution of plankton-derived POC in downstream waters compared with upstream reaches (Kendall et al., 2001). In Yellow River, the operation of the Xiaolangdi Reservoir substantially altered the composition of riverine POC transported downstream, increasing the proportion of soil-derived POC from 56.4% to 82.0% and decreasing the proportion of plant-derived POC from 43.6% to 18.0% (Lv et al., 2022).

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These findings indicate that the relative contributions of terrestrial POC sources were ~~driven~~ primarily regulated by the riverine sediment budget. A reduction in sediment load prompted a shift in the dominant OC component from petrogenic OC (derived from bedrock/soil erosion) to OC derived from aquatic productivity (Dai et al., 2016). This interpretation is consistent with our observation that total suspended matter concentration was positively correlated with petrogenic OC but negatively correlated with algae OC (Fig. S5). Two potential mechanisms~~interpretations~~ may ~~be involved in~~explain this alteration. On the one hand, a large amount of riverine sediment in the upper reaches~~upstream~~ of the Changjiang River, primarily derived from montane bedrock weathering and soil erosion, were intercepted by~~in~~ reservoirs after dam construction (Li et al., 2015; Lambert et al., 2017). Therefore, the proportion of OC derived from aquatic biomass in downstream sections increased because of ~~less~~ reduced mixing ~~of~~ with petrogenic OC. On the other hand, the decline in~~d~~ sediment load in the downstream~~ of the~~ Changjiang River may have~~, by~~ ~~increasing~~ increased light penetration~~transparency~~ into the water column, indirectly enhancing~~ed~~ aquatic productivity and ~~thus~~ thereby increasing the ~~higher~~ proportion of algae-originated OC (Robertson et al., 1993; Huettel et al., 2014). However, our current data are insufficient to determine which mechanism is dominant. Future studies combining seasonal observations of sediment load, light conditions, phytoplankton biomass would help better constrain the mechanisms driving changes in OC composition in the Changjiang River.

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We observed no ~~in~~significant differences ($p > 0.05$) in N/C molar ratios or $\delta^{13}C$ values between the dry and flood seasons (Fig. 2b, d), while this pattern may ~~be~~ have resulted~~derived~~ from the long-term averaging of our dataset. During ~~a~~ monthly monitoring conducted from September 2009 to August 2010 at Xuliujing Station (a Hydrological Gauging Station in the lower Changjiang River), the N/C molar ratios were higher in the flood season (0.099; 0.090–0.116) ~~relative to~~than in the dry season (0.086; 0.073–0.098), ~~and~~ whereas the $\delta^{13}C$ values were comparable between seasons (Gao et al., 2012). Similarly, Ming et al. (2023) reported that from November 2016 to June 2019 at Xuliujing Station, the N/C molar ratio in the flood season (0.112 ± 0.015) was clearly higher than that in the dry season (0.093 ± 0.013), whereas $\delta^{13}C$ values showed little seasonal variation. By comparison, across multiple sites in the lower reaches of the Changjiang River, Mao et al. (2011) found similar N/C molar ratios between the flood (0.109) and dry (0.118) seasons, with slightly lower $\delta^{13}C$ values in the flood season (-25.4‰ to -24.1‰) than in the dry season (-25.4‰ to -21.6‰). These contrasting findings across seasons and locations reveal pronounced temporal and spatial variability in the terrestrial sources of POC, underscoring the critical role of the river-estuary–ocean continuum in regulating the composition of river-delivered POC. Such variability may, in turn, exert an important influence on OC burial in subaqueous deltas, thereby highlighting the need for sustained, high-temporal-resolution monitoring.

4.2 Patterns of OC burial in the Changjiang subaqueous ~~Changjiang Delta~~delta

Burial efficiency of terrestrial OC in the Changjiang subaqueous ~~Changjiang Delta~~ delta is 12.6% estimated in our study (Fig. S4a). This indicates a large proportion of OC in sediment is reworked into seawater rather than being preserved over prolonged ~~preservation~~timescales, which ~~was~~ is primarily attributed to the desorption and decomposition of POC during sediment seaward transport (Sun et al., 2021; Sun et al., 2024). The burial efficiency of terrestrial OC (12.6%) in the Changjiang subaqueous ~~Changjiang D~~delta is similar with Zhao et al. (2021b), who revealed that the OC burial efficiency was 16% in East China Sea. Spatially, ~~the~~ OC burial efficiency exhibits marked heterogeneity ~~in~~ among different sedimentary ~~units~~environments, with higher values observed in the proximal delta ~~relative to~~than in offshore regions (Fig. S4a). This is in a good line with Wu et al. (2013), who reported that the burial efficiency of organic matter was higher in inner shelf sediment (24.7% versus 21.3% in the Delta front in our study) and lower in outer shelf sediment (10.7% versus 9.8% in the Prodelta, 9.6% in the Delta-shelf and 9.7% in the Shelf in our study). However, these estimated burial efficiencies were markedly lower than ~~individual~~ the burial efficiency of petrogenic OC (33–94%) (Sun et al., 2022). This suggests the petrogenic OC is~~being~~ comparatively resistant to degradation during sediment offshore transport, implying heterogeneous losses among different terrestrial POC sources. Our results also ~~denoted~~ showed that the higher OC ~~contents~~ concentrations were observed in the~~surface sediments in~~ Prodelta surface sediments, which ~~are~~ primarily ~~corresponding~~ corresponded to petrogenic OC components in terms of C/N and $\delta^{13}C$ end-member values (Fig. S6). These patterns underscore the need to account for source-specific ~~behaviors~~ dynamics when evaluating POC delivery.

Beyond assessing OC burial efficiency via OC loadings in riverine SPM and deltaic sediments, the ratios of terrestrial OC ~~contents~~ concentrations between SPM and surface sediments were~~as~~ also employed as a quantified metric (Blair and Aller, 2012). ~~This method can capture the preservation of terrestrial OC in solid phase from suspended sediment to deposition, which is well-suited for analyzing extensive published datasets of OC, given that the dataset of OC loadings is normally limited.~~ In our study, we calculated this metric and termed it "OC preservation efficiency" to distinguish from "burial efficiency" (Section 2.~~5~~4). Unlike surface-area-normalized OC burial efficiency, this content-based metric does not explicitly normalize OC loading to sediment SA. This distinction is mechanistically important because sedimentary OC concentrations are controlled not only by degradation and preservation processes, but also by sediment grain-size sorting and mineral surface area. Fine-grained sediments generally have larger SA and greater capacity for mineral-associated OC protection, whereas coarser sediments tend to have lower OC retention capacity (Bergamaschi et al., 1997; Bock and Mayer, 2000; Babakhani et al., 2025). Therefore, variations in sediment texture may partly influence the calculated OC preservation efficiency and introduce uncertainty when environments with substantially different grain-size compositions are compared.

Nevertheless, the content-based preservation efficiency remains a useful metric for evaluating terrestrial OC retention, because the main objective of our study is to examine changes in terrestrial OC concentrations from riverine SPM to deposited sediments during seaward transport. Moreover, the OC content-based apparent preservation efficiency was tightly correlated with the OC/SA-based burial efficiency ($p < 0.001$; Fig. S4b), indicating that this metric provides an assessment broadly consistent with the surface-area-normalized burial efficiency approach. This relationship supports its use as an alternative indicator of terrestrial OC retention, particularly when sediment SA or OC loading data are unavailable. This advantage is important for integrating extensive published datasets, as OC concentrations in riverine SPM and surface sediments are much more commonly reported than sediment SA and OC loading data. Thus, although the content-based preservation efficiency should be interpreted as an apparent metric that may partly include grain-size effects, it remains appropriate for assessing temporal changes in terrestrial OC retention and loss in the Changjiang subaqueous delta.

We found that the OC preservation efficiency is similar to the burial efficiency of terrestrial OC (12.6%), yielding values of 11.2% in the Changjiang subaqueous delta~~. Moreover, the OC preservation efficiency is tightly linked to the OC burial efficiency ($p < 0.001$) (Fig. S4b), denoting that preservation efficiency serves as an alternative proxy for the degree of riverine POC retention/loss. However, the estimated OC preservation efficiency (11.2%) in subaqueous Changjiang Delta~~, which is notably lower than approximately 28% estimated in Blair and Aller (2012). This can be ascribed to the fact that our study accounts for distinct sedimentary ~~units~~environments, rather than treating the marginal system as an entity. We observed higher OC preservation efficiency in proximal deltaic areas when compared with offshore regions, with burial efficiencies reaching 25–40% in the Delta front and Prodelta, where sediments are predominantly fine grained (Fig. 1d; Fig. 4a). Sediment grain size is closely linked to OC retention capacity, as fine-grained sediments generally exhibit higher OC loading due to their greater specific surface area and stronger mineral-associated protection by~~associated with~~ constituent minerals (e.g., quartz, feldspar, calcite, and phyllosilicates) (Bao et al., 2019; Sun et al., 2022; Sun et al., 2024). These results highlight the importance of distinguishing different sedimentary environments~~critical role of sediment characteristics~~, as they are characterized by distinct sediment properties shaped by hydrodynamic processes (Table S4), which in turn influence OC sequestration in deltaic sediments.~~sorted by hydrodynamic processes across different sedimentary units, in controlling OC sequestration in deltaic sediments.~~

Advanced from spatial pattern of OC preservation efficiency in the Changjiang subaqueous ~~Changjiang d~~Delta, we further~~ly~~ investigated its temporal changes. We found that the OC preservation efficiency decreased visibly from 15.1% prior to 2003 to average 10.7% after 2003 (Fig. 4c). This implied that the river-delivered POC after 2003 is more prone to decompose during ~~sediment~~ transport, primarily due to the increased proportion of freshwater algae OC over time (Fig. ~~2a~~2e; Fig. S3~~2~~). The ~~algae~~ algal OC components, ~~generally~~ derived from aquatic primary productivity, was composed of algae cells, debris and aggregates, enriching in proteins, carbohydrates (e.g., polysaccharides) and lipids (Henderson et al., 2008; Villacorte et al., 2015). These components are easily degraded and assimilated through biological processes (Guo et al., 2025). The ~~T~~temporal~~ly~~ decrease~~d~~ in the terrestrial OC proportion ~~of OC~~ in the Delta front, from 91.8% before 2003 to 64.9% after 2003 (Fig. S7), also verified that a larger amount of riverine POC was decomposed prior to burial, consistent with the deviation of OC characteristics from typical algal-derived organic matter ~~components~~ signatures (Fig. 3a).

In addition, the temporal decline in OC preservation efficiency in the Changjiang subaqueous ~~Changjiang Delta~~ delta was primarily driven by ~~decreases~~ decreased ~~in~~ preservation efficiency in the Delta front (from 21.7% to 16.5%) and Prodelta (from 21.6% to 14.9%) between the pre-2003 and post-2003 periods. This suggests that, in nearshore regions of the Changjiang

Estuary, fine-grained sediment with high OC loading~~ fine grain sediment~~s (mainly petrogenic OC) ~~was ~~may have been progressively ~~constantly ~~washed away into distal regions, with less replenishment ~~through ~~because of reduced riverine sediment ~~load~~supply. Given the decreased riverine petrogenic OC input and coarser sediment grain size (Fig. 1g; Fig. 2e), we infer~~red~~ that the OC preservation efficiency in proximal delta will continue to decline in the future. In addition, although our data are insufficient to directly quantify this effect, temporal sediment coarsening in the Changjiang subaqueous delta may have partly contributed to the decline in apparent OC preservation efficiency. This effect is likely more pronounced in the proximal delta, where reduced riverine sediment supply after the construction of the Three Gorges Dam in 2003 has been linked to erosion and sediment coarsening (Fig. 1g; Wu et al., 2025). Because coarser sediments generally have a lower capacity for OC retention, such coarsening could reduce sedimentary OC concentrations and contribute to the observed decline in OC content-based preservation efficiency.

Riverine POC flux declined significantly ($p < 0.01$) by 49% from 0.45 Mt/month in July 2001 before the Three Gorges Dam construction to an average~~d~~ of 0.23 Mt/month in flood seasons from 2011 to 2020 as expected with the temporal reduction of sediment load (Fig. 1~~f~~g; Fig. 4d). This estimation ~~wa~~is ~~consistent ~~comparable to that of~~with~~ Wang et al. (2022), who ~~revealed~~ reported a POC flux of 0.21 Mt/month in flood seasons from 2013–2014 and 2018–2019. By considering OC preservation efficiency in different periods, we further~~ly denoted ~~identified a visible decrease ($p < 0.01$) in the amount~~s~~ of OC preserved in sediments by 50%, from ~~0.068~~68 k~~M~~t/month in 2001 to an average~~d~~ of ~~0.034~~34 k~~M~~t/month ~~in ~~during the flood seasons from 2011 to 2020 (Fig. 4d). This decline likely reflects the preferential degradation of algal POC during seaward transport, as indicated by deviations in end-member values (C/N, $\delta^{13}C$) between surface sediments and SPM (Fig. 3~~a; Fig. S2~~). It is further supported by the temporal decline in~~low~~ the proportion of terrestrial OC preserved in proximal deltaic deposits, particularly in the ~~delta ~~Delta front of the Changjiang subaqueous ~~Changjiang Delta ~~delta (Fig. S7~~a~~). Future studies should account for temporal variations in the contributions ~~from ~~of different terrestrial sources of riverine POC when evaluating deltaic OC burial in other large estuarine systems.

4.3 Loss of labile POC during sediment transport

~~Despite~~Although previous investigations have~~d~~ found that river damming predominantly changes~~d~~ contributions of different sources ~~for ~~of POC (Kendall et al., 2001; Pradhan et al., 2014; Bianchi et al., 2015; Ulseth and Hall Jr., 2015; Lv et al., 2022; Lyu et al., 2023; Wang et al., 2024; Hu et al., 2025; Ke et al., 2025), to the best of our knowledge, limited studies have explored the influence of this alteration on terrestrial OC burial in marginal seas. By compiling a dataset of riverine POC characteristics in the Changjiang Estuary since 1980, prior to dam constructions in the upper mainstem (Gezhouba Dam and Three Gorges Dam) (Table S1), we ~~unveiled ~~reveal that the proportion of labile POC (primarily derived from freshwater algae) input ~~in~~to the East China Sea increased continuously over time (Fig. 2e), ~~and ~~thereby~~thus~~ decreasing~~ed~~ OC preservation efficiency and ~~less ~~reducing OC retention in deltaic sediments. Globally, riverine sediment fluxes have declined sharply over time due to intensified anthropogenic activities such as dam construction~~s~~ (Dethier et al., 2022). These reductions in sediment loads not only diminish OC burial in marginal seas by directly lowering riverine POC fluxes, but may also enhance OC degradation during seaward transport by improving the relative contributions of labile OC fractions. To clarify the loss of labile OC along its offshore transport, we analyzed contrasts in OC-related metrics between SPM and surface sediments.

Specific surface area (SA), which is generally higher in fine-grained sediments, is considered a key factor controlling OC retention capacity (Bergamaschi et al., 1997; Bock and Mayer, 2000; Yang et al., 2015). Our results also found that the SA was closely associated with~~to~~ MGS in both SPM and surface sediments from~~in~~ the Changjiang Estuary (Fig. 5a), whereas it exhibited opposite relationships with OC ~~content~~ concentrations and $\Delta^{14}C$ between SPM and surface sediments (Fig. 5b, c). In surface sediments, ~~The~~ SA ~~of surface sediments~~ was positively correlated with both OC ~~content~~ concentrations and $\Delta^{14}C$, suggesting that mineral protection plays an important ~~primary~~ role in the initial stabilization of OC. However, this influence weakens progressively offshore (from the Delta ~~Front~~ front to the Shelf), likely due to repeated cycles of sediment resuspension and deposition under dynamic estuarine conditions, which ultimately promote the loss and aging of sedimentary OC (Sun et al., 2021). In contrast, ~~the~~ OC concentrations~~content~~ in SPM decreased with increasing SA and aging of OC, suggesting a clear mixing between petrogenic OC (older and carbon-poor) and algal OC (younger and carbon-rich). Unfortunately, the lack of $\Delta^{14}C$ measurements in SPM across different years limits our ability to further~~ly~~ ~~prove~~ demonstrate the temporal shift in dominant ~~sources of~~ terrestrial OC sources. The ~~V~~vanish of these younger, OC-enriched components in surface sediments indicates the preferential decomposition of labile algal OC prior to deposition. Over time, the increasing proportion of freshwater algal OC in SPM may further enhance~~s~~ the overall lability of OC derived from these easily degradable biospheric POC (Zhao et al., 2023), ultimately resulting in reduced OC burial in the Changjiang subaqueous ~~Changjiang Delta~~delta.

Ratios of OC to SA (OC/SA) in sediments, reflecting OC loading in per unit surface area of sediment (mg C/m^2), were assessed to represent potential remineralization of OC during sediment transport and OC burial (Bouchez et al., 2014; Sun ~~GCA~~ et al., 2021). Typical OC/SA ratios in marginal sediments ranged from 0.5 to 1 mg C/m^2 (Mayer, 1994; Hedges and Keil, 1995; Blair and Aller, 2012; Bianchi et al., 2018).

This range was comparable ~~with~~ to our results ~~(0.23–1.33)~~ ~~in~~ for surface sediments (0.23–1.33) in the Changjiang subaqueous ~~Changjiang Delta~~delta, while it was markedly lower than the OC/SA values of~~in~~ SPM (2.4 ± 0.7) collected ~~in~~ from the inner Changjiang Estuary (Fig. 1e). Given that the ~~protection~~ protective effect ~~to~~ on OC is commonly ~~derived from~~associated with sediment ~~the~~ mineral composition ~~in sediments~~, similar mineralogies would be expected to result in comparable OC loadings. Although ~~the~~ clay mineral assemblages are comparable between riverine SPM and surface sediments (Sun et al., 2022), the markedly higher OC loading in SPM suggests that SPM may contain a larger ~~fraction~~ proportion of relatively labile OC, which is ~~unprotected by minerals and thus~~ more susceptible to loss during sediment transport. To ~~trace~~ investigate the burial patterns of OC ~~in~~ from different sources across sedimentary ~~units~~environments, we ~~established~~ examined the relationships between OC/SA and C/N, $\delta^{13}C$ and $\Delta^{14}C$. ~~We found that t~~The $\delta^{13}C$ ~~exhibited~~ showed a weak ~~relationship~~ association ($p > 0.05$) with OC/SA (Fig. 5e), ~~while the~~whereas C/N and $\Delta^{14}C$ were positively and negatively ~~associated~~ correlated ($p < 0.05$) with~~to~~ OC/SA, respectively (Fig. 5d, f). In the Delta front, the OC was characterized by lower $\Delta^{14}C$, higher C/N ratios and higher OC/SA (Fig. 5d, f), suggesting preferential deposition of relatively old, coarse-grained terrestrial OC in the proximal delta. This material likely consists mainly of coarse petrogenic fragments and C3 plant debris derived from the river basin (Sun et al., 2021; Sun

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et al., 2022). In contrast, in the Prodelta, Delta-shelf and Shelf, the OC was characterized by higher $\Delta^{14}C$, lower C/N and lower OC/SA (Fig. 5d, f), indicating a relatively younger, fine-grained mixture of petrogenic and marine OC in the distal delta. This mixture was likely supplied by catchment soil erosion and marine primary production (Zhu et al., 2013; Sun et al., 2021), as further supported by the overlap of many samples with both petrogenic and marine OC end-member ranges (Fig. 3b–d). The aged OC, characterized by lower SA and OC content but higher C/N ratios (> 8), was predominantly deposited in the proximal subaqueous delta and identified as coarse C_3 plant debris originating from the river basin (Zhu et al., 2013; Sun et al., 2021). In contrast, younger OC displayed higher SA and OC content with lower C/N ratios (< 8) and was primarily found in the distal delta, comprising lithogenic detritus from watershed bedrock erosion and inputs from marine primary production (Fig. 3). Despite the multiple sources of OC, these differences, identified characteristic of freshwater algal OC signatures, as indicated by (C/N, $\delta^{13}C$ and $\Delta^{14}C$,) (Fig. 3; Fig. 5f), were largely absent from both proximal and distalin deltaic sediments (Fig. 3; Fig. 5f), implying that this OC component undergoesthe preferential loss of this OC component prior to burial during seaward transport prior to burial.

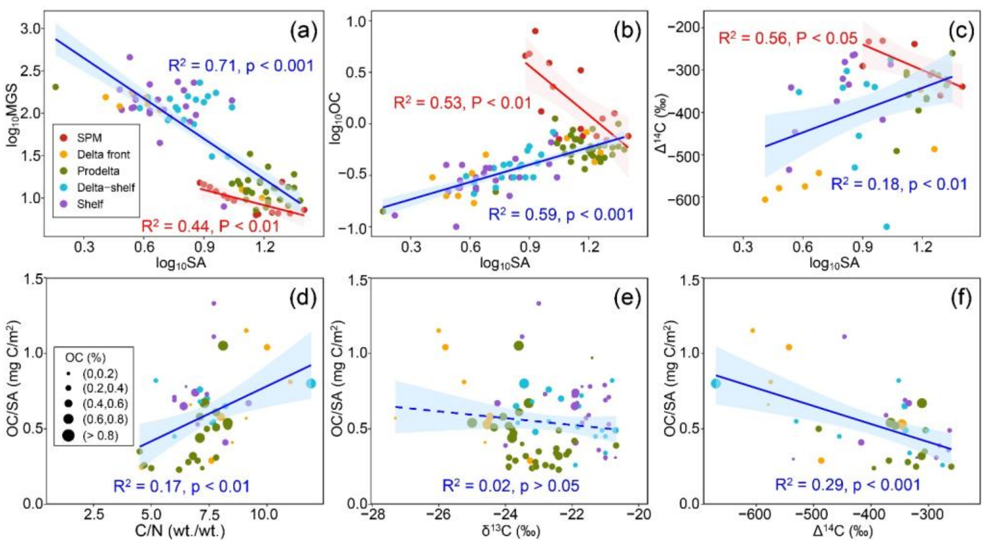

Figure 5 Factors controlling organic carbon (OC) contents concentrations and loadings in suspended particulate matter (SPM) of from the Changjiang Estuary and surface sediments fromin the Changjiang subaqueous Changjiang Deltadelta. Relationships between specific surface area (SA) and medium grain size (MGS) in SPM and surface sediments (a). Relationships between SA and OC content concentrations in SPM and surface sediments (b). Relationships between the OC/SA and C/N in SPM and surface sediments (c). Relationships between the OC/SA and C/N (d), $\delta^{13}C$ (e) and, $\Delta^{14}C$ (f), respectively, in surface sediments. The sSolid and dashed lines indicate statistically significant ($p < 0.05$) and insignificant ($p > 0.05$) relationships, respectively, and the light blue and red shaded areas around the lines represent 95% confidence interval.

5 Conclusions

This study reveals that the decline in sediment load of the Changjiang River since 1980 has led to a temporal increased N/C molar ratio and decreased $\delta^{13}C$ values of POC delivered to the East China Sea. These changes reflect a decreasing proportion of POC derived from soil/bedrock erosion and a growing contribution of POC originating from freshwater primary production, suggesting enhanced degradation of labile algal OC during seaward sediment transport and consequently reduced OC burial in the subaqueous delta. The reduction ~~of~~ in terrestrial OC burial mainly occur~~s~~red in ~~the~~ proximal deltaic sediments, where ~~the~~ OC preservation efficiency in the Delta front ~~dropping~~ dropped notably from 21.7% to 16.5% following the impoundment of the Three Gorges Dam in 2003. This trend is further evidenced by the pronounced decline in terrestrial OC components and the ~~improving~~ increasing dominance of petrogenic OC in Delta front sediments. As a result, the OC preservation efficiency across the entire Changjiang subaqueous ~~Changjiang Delta~~ delta declined~~decreased~~ ~~by approximately 1.5-fold,~~ from 15.1% before 2003 to 10.7% afterward. Consequently, the amount of OC preserved in sediments declined ~~approximately~~ by approximately 50%, from ~~0.68 × 10^5~~68 kt/month in 2001 to an average of ~~0.34 × 10^5~~34 kt/month during 2011–2020. Our study demonstrates that, in the context of intense anthropogenic disturbance, ~~assessing~~ assessment of deltaic OC burial should consider~~requires consideration not only in~~ the decline ~~of~~ in terrestrial POC flux caused by basin dam constructions, but also shifts in POC sources, since the stability of POC varies markedly among its different components, thereby altering the efficiency of OC burial in the subaqueous deltaic systems.

Data availability

~~Data will be available from the corresponding authors upon reasonable request.~~All data supporting this study are available from Zenodo at: https://doi.org/10.5281/zenodo.20260902.

Supplement link

The link to the supplement will be included by Copernicus, if applicable.

Author contributions

Jiyuan Jin: Designation of this study, Data compilation & processing, Methodology & Software, Writing original draft preparation, Writing-review & editing. Ya Ping Wang: Project administration, Supervision, Writing-review & editing. Hui Sheng: Project administration. Bixuan Tang: Investigation. Wei Feng: Writing-review & editing. Lanyue Liu: Investigation. Rui Liu: Investigation.

Competing interests

The authors declare that they do not have any competing interests that could have appeared to influence the work reported in this paper.

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