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Sedimentary BSi and TOC quantifies the degradation of the Changjiang Estuary, China, from river basin alteration and warming SST

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A B S T R A C T

Environmental degradation in the Changjiang Estuary has recently become a global topic, given its proximity to Shanghai with a population >23 million. Intensification of human activities affecting the river basin is responsible for this degradation. Dam construction has cut off ca. 2/3 of the sediment flux to the sea, ca. 60% of the dissolved silicate load (DSi) has been retained in the reservoirs, while total phosphorous (TP) and total nitrogen (TN) transport to the sea are many times more than they were a few decades ago. Under such circumstances, details of the estuarine degradation remain poorly understood. This study uses sedimentary biological silicate (BSi) and total organic carbon (TOC) as environmental proxies to reveal the process-response of such degradation since the 1950s. Our results demonstrate the spatial differences of such degradation. The inner zone of the estuary used to be highly turbid, but presently has increasing diatom (BSi) and primary production (TOC), due to lower suspended sediment concentration (SSC) in relation to dam construction. In contrast, increasing riverine dissolved inorganic nitrate (DIN) and dissolved inorganic phosphorous (DIP) input (up to 2–5 times) and decreasing DSi provide a unique setting, with an excess in N and P, which catalyzes non-diatom algae in the less-turbid middle zone of the estuary. These are reflected by decreasing BSi and BSi/TOC since the 1950s, together with an increase of TOC of 20–40%. In the outer zone of the estuary, increasing DIN, DIP, and sea surface temperatures (SSTs), have resulted in the increase of diatom biomass by 15–20% and the growth of primary production by 30–60% since the 1950s. But the drastic decrease in DSi, Si/N, and Si/P depresses the ability of diatoms to develop, resulting in a reduction of 5–10% diatom proportion (BSi/TOC) since the 1930s. This study improves the understanding of the changing estuarine ecosystem in response to global change.

1. Introduction

In recent decades, estuaries have been exhibiting ecological degradation much more than ever before, due to intensifying anthropogenic activities in river basins, e.g., increasing dam construction, fertilizer application, and climate warming (Nixon, 1995; Cloern, 2001; Milliman and Farnsworth, 2013). This has catalyzed a dramatic increase in primary production in estuarine waters (Lohrenz et al., 2008; Zhou et al., 2008), leading to the weakening of ecosystem services, the loss of biodiversity, and the decline of water quality. (Diaz and Rosenberg, 2008; Conley et al., 2009).

Ecological degradation of river mouth systems has been illustrated by recent studies of the Mississippi Estuary. Presently, the estuary is receiving ca. 1.2×10^8 t a^{-1} sediment load from the river basin, which is far less than in previous decades (2.5×10^8 t a^{-1}) (Meade and Moody, 2010). At the same time, TN and TP in the river mouth have doubled, but DSi decreased by ca. 50% (Turner and Rabalais, 1994). Another example is in the Nile River, where serious ecological degradation has happened recently. The increase TN and TP in the estuary results from excessive fertilizer use in the river basin, while the Aswan dam, completed in 1964, has cut off most of the sediment flux to the estuary. Nixon (2003) reports a 90% decrease in DSi. These changes have exerted multiple stressors on the sustainable development of the estuarine setting, on which human welfare is dependent.

The environmental changes in the Changjiang River have become a global topic because the river basin is densely populated (>400 million) and has experienced rapid economic development in the past 35 years. Intensification of industry and agriculture has negatively impacted on estuarine ecology, which has been further

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aggravated by rising sea surface temperature (SST) in response to the globally warming climate. This impact is represented by the hypoxia zone in the river mouth area and adjacent sea, which has expanded in recent years (Zhu et al., 2011).

The Changjiang River supplied ca. 4.7×10^8 t a^{-1} of sediment to the estuary during the 1950s and 1960s, but this has decreased to 3.7×10^8 t a^{-1} because of dam construction during the 1970s–1990s. The Three Gorges Dam, completed in 2003, has further reduced sediment load to ca. 1.5×10^8 t a^{-1}, accordingly decreasing suspended sediment concentration (SSC) in the estuarine water by ca. 50%. Nutrient fluxes from the Changjiang River have greatly increased since the late 1970s. TN and TP loads entering the river mouth are now significantly higher than they were decades ago (Duan et al., 2008), but DSi has been reduced due to dam construction (Li et al., 2007). This has altered the ratio of nutrients in the estuarine waters, causing a change in the dominant algae from diatom to non-diatom species (Li et al., 2007; Zhou et al., 2008). Consequently, serious environmental issues occur in the river mouth area, such as heavy eutrophication and increasing Harmful Algae Blooms (HAB) (Zhou et al., 2008; Jiang et al., 2010).

Although widely studied, the processes and drivers of environmental degradation in the Changjiang Estuary remain poorly understood. This study uses sedimentary BSi and TOC, retrieved from estuarine core sediments, as sensitive environmental proxies to: 1) reveal the spatiotemporal variations of BSi and TOC in the core sediments covering the entire estuary, 2) define key drivers of environmental degradation by means of quantitative analysis of these environmental proxies, and finally, 3) establish a process-response model in relation to both the change in the river-basin surface and warming SST. The results will provide insights for comparable studies in other estuaries in the near future.

2. Data source and methods

2.1. Iso-transparency and sediment cores

On the basis of iso-transparency data (July) collected from the Marine Atlas (EBMAMH, 1992), the estuarine study area can be divided to 3 zones: the inner (I: <1 m), middle (II: 1–4 m) and outer (III: >4 m) (Fig. 1).

Five shore sediment cores (A2, A4, A5, X38, X21), drilled in 2006 and 2013, were used for this study (Fig. 1). Another 5 shore sediment cores (E2, E4, Z5, Z7, GC) were sourced from Xu (2004), Lv (2007), Zhou (2008) and Zhu et al. (2014) (Fig. 1). These 10 sediment cores were sited at the inner, middle, and outer zones of the Changjiang Estuary (Fig. 1). All sediment cores were obtained by gravity corer and were sampled at 1–2-cm intervals for laboratory analysis. Samples were frozen prior to analysis. For details of the core sediment, see Table 1.

2.2. Grain size analysis

Grain size was analyzed for 4 sediment cores (A2, A4, A5, X21). In total, 346 sediment samples were tested by Laser Particle Analyzer (Beckman Coulter LS13320), ranging from 0.04 to 2000 μm, with a standard deviation of 8.03 ± 2.25 μm.

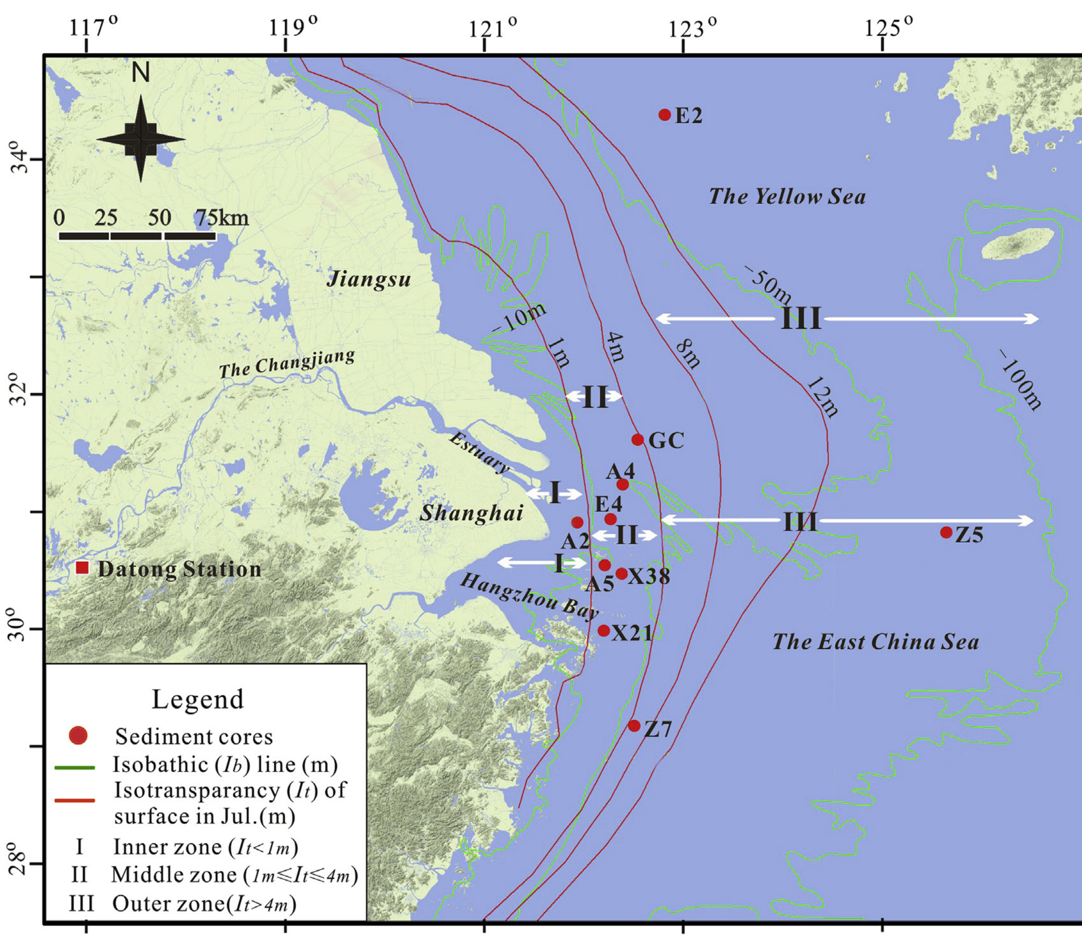

Fig. 1. Study area – The Changjiang River estuary indicating 1) the sites of sediment core, and 2) the three zones (inner, middle and outer), on the basis of iso-transparency sourced from EBMAMH (1992).

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