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Decadal morphological evolution of the Yangtze Estuary in response to river input changes and estuarine engineering projects

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ABSTRACT

The Yangtze Estuary in China has been intensively influenced by human activities including altered river and sediment discharges in its catchment and local engineering projects in the estuary over the past half century. River sediment discharge has significantly decreased since the 1980s because of upstream dam construction and water-soil conservation. We analyzed bathymetric data from the Yangtze Estuary between 1958 and 2010 and divided the entire estuary into two sections: inner estuary and mouth bar area. The deposition and erosion pattern exhibited strong temporal and spatial variations. The inner estuary and mouth bar area underwent different changes. The inner estuary was altered from sedimentation to erosion primarily at an intermediate depth (5–15 m) along with river sediment decline. In contrast, the mouth bar area showed continued accretion throughout the study period. The frequent river floods during the 1990s and simultaneously decreasing river sediment probably induced the peak erosion of the inner estuary in 1986–1997. We conclude that both sediment discharge and river flood events played important roles in the decadal morphological evolution of the Yangtze Estuary. Regarding the dredged sediment, the highest net accretion rate occurred in the North Passage where jetties and groins were constructed to regulate the navigation channel in 1997–2010. In this period, the jetties induced enhanced deposition at the East Hengsha Mudflat and the high accretion rate within the mouth bar area was maintained. The impacts of estuarine engineering projects on morphological change extended beyond their sites.

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1. Introduction

Estuaries and deltas are of great ecological and socio-economic significances because many of the largest cities are located in their vicinity (Woodroffe et al., 2006). With increasing global climate changes due to both natural and anthropogenic factors, the morphological response and future trends of estuaries and deltas, particularly on the decadal time scale, have become a public concern. Our understanding of these issues can bridge the knowledge gap between short-term seasonal to annual processes and long-term centennial to millennial evolution, and provide sustainable strategies to policy makers for the integrated management of these dynamic systems.

The morphological evolution of river deltas is controlled by natural forcing such as rivers, tides, waves, and sea-level conditions and influenced by anthropogenic activities such as upstream dam construction, land reclamation, navigational works and dredging (Wang et al., 2015). Syvitski et al. (2005) suggested that the net global reduction of sediment flux into coastal oceans resulting from human impacts is approximately 1.4 billion tons per year, and that approximately 20% of global sediment flux is trapped in large reservoirs. An analysis based on a dataset of 145 major rivers worldwide revealed that nearly half of the rivers experienced reduced sediment flux primarily caused by sediment retention by reservoirs (Walling and Fang, 2003), triggering the regression of subaqueous deltas (Milliman, 1997; Syvitski et al., 2009; Yang et al., 2011). Human interferences including the flow-path management of distributary channels and mitigation of seasonal flood waves, are now playing increasingly important roles in the evolution of deltas (Syvitski and Saito, 2007).

A number of case studies have been conducted on deltas worldwide. The Nile Delta, with 50 million people living nearby, is perhaps the world's most typical example of human control on sediment discharge because of the construction of the High Aswan Dam in 1964. Lake Nasser entrapped nearly all (>98%) of the sediment (Shalash, 1982), leading to complete depocenter alteration and the conversion of the delta from a deposition environment to an erosion one (Stanley, 1996). Another example is the Mississippi River Delta, which has reverted from net progradation to land-loss since the late 19th century with land-loss rate acceleration in the 20th century, primarily because of engineering structures, rapid subsidence and global sea-level rise (Gagliano et al., 1981; Blum and Roberts, 2009). The total land loss in coastal Louisiana was as substantial as 4920 km^2 from 1932 to 2000 according to the

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report by the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) and U.S. Geological Survey (USGS) (http://www.lacoast.gov/LandLoss/). As a result of this land loss, Hurricanes Katrina and Rita caused greater damage and human tolls in 2005, confirming that human activities exacerbated the vulnerability of Louisiana coastal communities (Day et al., 2007). A recent study on the Mekong Delta also indicated erosion in response to river sediment decline (Anthony et al., 2015). A synthesis of the world's large rivers regarding their morphology and management by Gupta (2007) provided a comprehensive interconnection between controlling factors of large rivers. Currently, the features and mechanisms of delta responses to global climate changes are not well understood. Additionally, the morphological evolution in the coming decades remains largely uncertain. Thus, knowledge of the decadal morphological evolution of deltas and estuaries is urgently needed.

The Yangtze Estuary in China is intensively influenced by human activities including altering river discharge and sediment load in the catchment and local engineering projects in the estuary (De Vriend et al., 2011). It provides a useful example for identifying how estuarine morphology has responded to human interferences. >50.000 dams

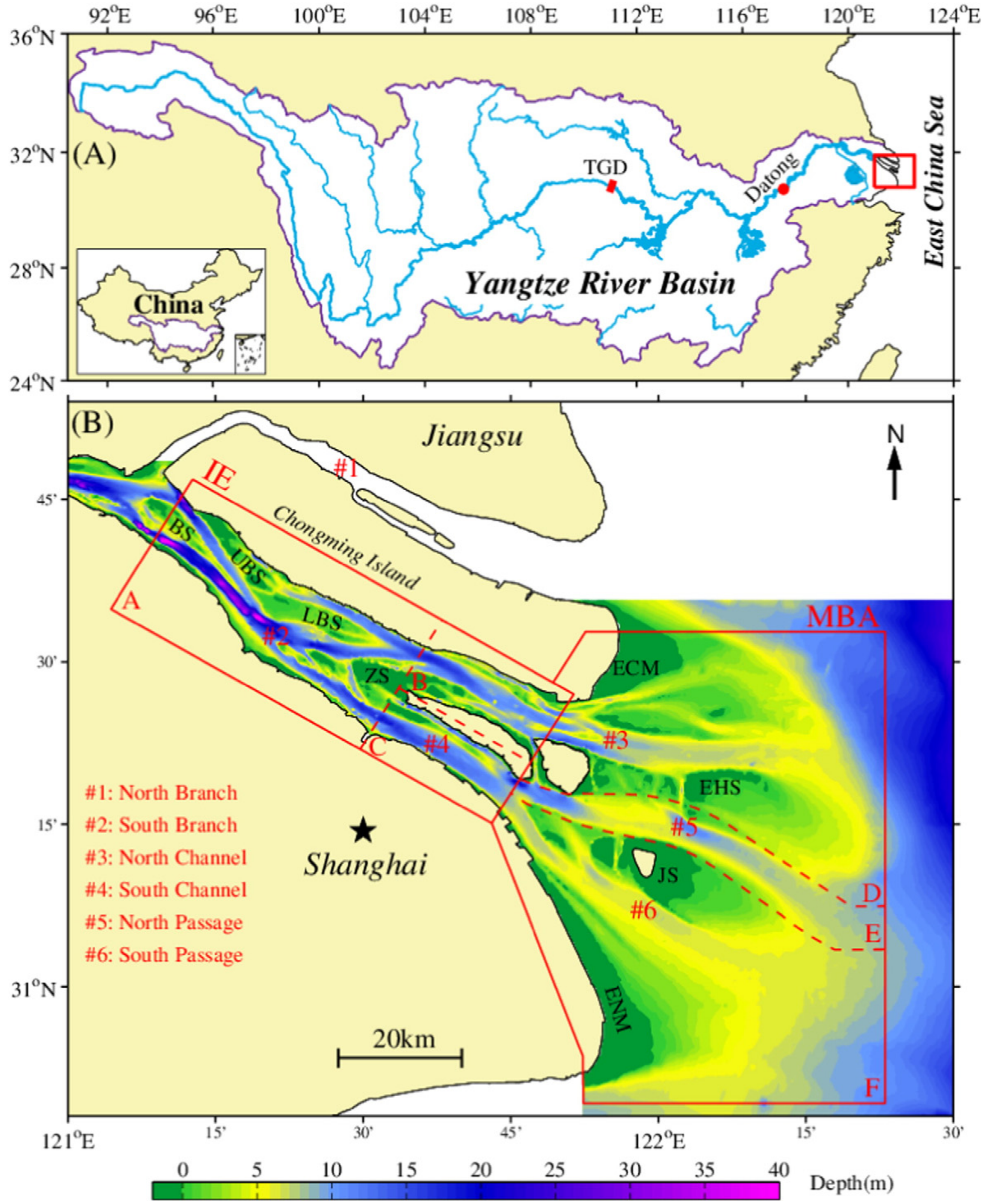

Fig. 1. Map of the study area. (A) The locations of the Yangtze Estuary (rectangle) and Yangtze River Basin (white area). (B) The Yangtze Estuary with its bathymetry in 1997. The study area is divided into the inner estuary (IE) and mouth bar area (MBA) by solid lines. The IE and MBA are further divided into three sub-areas by dashed lines (see text for more information). TGD: Three Gorges Dam; BS: Baimao Shoal; UBS: Upper Biandan Shoal; LBS: Lower Biandan Shoal; ZS: Zhongyang Shoal; ECM: East Chongming Mudflat; EHS: East Hengsha Shoal; JS: Jiuduan Shoal; ENM: East Nanhui Mudflat.

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