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Linking the infilling of the North Branch in the Changjiang (Yangtze) estuary to anthropogenic activities from 1958 to 2013

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ABSTRACT

Many tidally-dominated estuaries of the world are experiencing variations in bottom topography due to changes in natural forcings and intensive human activities. Here we focus on the morphological evolution of the North Branch (NB), a tidally-dominated distributary of the Changjiang estuary. Our analysis is based on long-term bathymetric and hydrological data collected between 1950 and 2010. The results show that mean water depth, channel volume below 0 m, and channel volume below −5 m have respectively decreased by 43%, 53% and 92% in the last 50 years. A reduction of the whole estuarine surface with aggradation in elongated tidal sand bars and erosion at the mouth are the main morphological variations of the NB, while a decrease in channel volume below −5 m due to infilling is the second mode of morphological change. While the drastic decrease in sediment load from upstream is likely unrelated to the silting of the NB, local land reclamation along the banks is directly responsible for the reduction of estuarine surface area and related tidal prism. Between 1958 and 2013, enhanced flood-tide currents resulted in a large import of sediments from offshore into the NB, triggering a sustained decrease in channel volume below 0 m. It is argued that the recovery of the funnel-shaped configuration of the estuary by restoring mud flats over 0 m, dredging the southern part of the estuary bend and forbidding land reclamation could prevent the silting of the NB, otherwise the NB will likely vanish in few decades.

1. Introduction

Estuaries are interfaces between fluvial upland systems and wave- or tide-dominated regimes of the open coast, resulting in complex sediment- and morpho-dynamics (Van der Wal et al., 2002). Because of their location and ubiquity, estuaries play a vital role in the fluxes of water and nutrients between lands and oceans, thus providing economically and ecologically indispensable goods and services to communities (USEPA, 1993; Capo et al., 2006). Most estuaries of the world are facing severe challenges due to anthropogenic activities, such as dam construction, sand excavation, and land reclamation (Van der Wal et al., 2002; Kim et al., 2006; Anthony et al., 2015). Many estuaries formed when sea level rose >100 m from the last glacial lowstand to its present level about 6000 years ago (Wolanski, 2006; Perillo, 1995; Heap et al., 2004). In spite of their millennial life-span (Roy et al., 2001), several estuaries worldwide have experienced drastic morphological changes, and few still preserve the original broad intertidal area due to land reclamation carried out in the last century (Woodroffe, 2003; Wolanski, 2006). Reduction in intertidal area and related tidal prism has often resulted in the infilling of the estuary, leading to navigation problems and habitat modification (Van der Wal et al., 2002; van der Wegen et al., 2010; Morris, 2013; Canestrelli et al., 2014).

Bathymetric variations in estuaries are determined by wave climate, the availability of riverine and coastal sediments, and fluvial and tidal hydrodynamics (Wright and Coleman, 1973). Some studies further indicate that sediment dynamics in many tidally-dominated estuaries are controlled by the asymmetry between flood and ebb (Postma, 1961; Aldridge, 1997), gravitational circulation (Uncles and Stephens, 1997), and tidal pumping (Wolanski and Spagnol, 2000; Mitchell et al., 2003). In recent decades anthropogenic activities have had a dramatic effect on the morphology of estuaries, modifying the hydrodynamics and the extension of intertidal flats (van Der Wal and Pye, 2004; Kim et al., 2006; Liu et al., 2007; Cuvilliez et al., 2009). Cuvilliez et al. (2009) indicate that the tidal prism within the Seine estuary had reduced by >31% from 1978 to 2005 due to sand accumulation in the channel. Kim et al. (2006) showed that the macro-tidal Keum river estuary in the eastern Yellow Sea has undergone siltation and morphological change since 1994 because of extensive coastal development. Spearman et al. (1998) indicate that considerable siltation with a net loss in tidal volume of around 50% was measured in the muddy estuary of the River Lune, UK, because of the construction of seawalls and dredging activities. A similar outcome was observed in the Mersey estuary after the

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construction of a seawall, with significant bottom accretion between 1906 and 1977 (Thomas et al., 2002).

More estuaries could become unstable and respond much faster to human disturbances in the future (Wolanski, 2006). To better address these dynamics, laboratory experiments (Tambroni et al., 2005), numerical models (Lanzoni and Seminara, 2002; Todeschini et al., 2008; de Swart and Zimmerman, 2009; Pittaluga et al., 2014; Canestrelli et al., 2010, 2014), analytical methods (Seminara et al., 2010), and hydrological and morphological investigations (Van der Wal et al., 2002; Kim et al., 2006) have tried to address morphological equilibrium in tidally-dominated estuaries, where upstream water and sediment discharges are negligible. Because of the combination of complex hydrological conditions and increasing human manipulations of these systems in recent decades, more studies are required to understand the coupling between estuarine sediment budget and morphological change. It is vital to discern causes of estuarine siltation and predict the long-term morphological evolution of estuaries, especially in the Changjiang Estuary, the largest estuary in China.

The Changjiang (Yangtze) River is the longest river in Asia and the third-longest in the world with a length of around 6300 km, having a mean water discharge of 905×10^9 m^3/year and a mean sediment discharge of 0.43×10^9 ton/year in the period 1950–2000 (BCRS, 2010). In the lower reaches of the Changjiang, the river channel bifurcates at four islands, Chongming, Hengsha, Changxing and Jiuduan Shoal (Fig. 1a), forming a 3-tiered branching delta that has 4 distributary mouths debouching in the East China Sea (North Branch, North Channel,

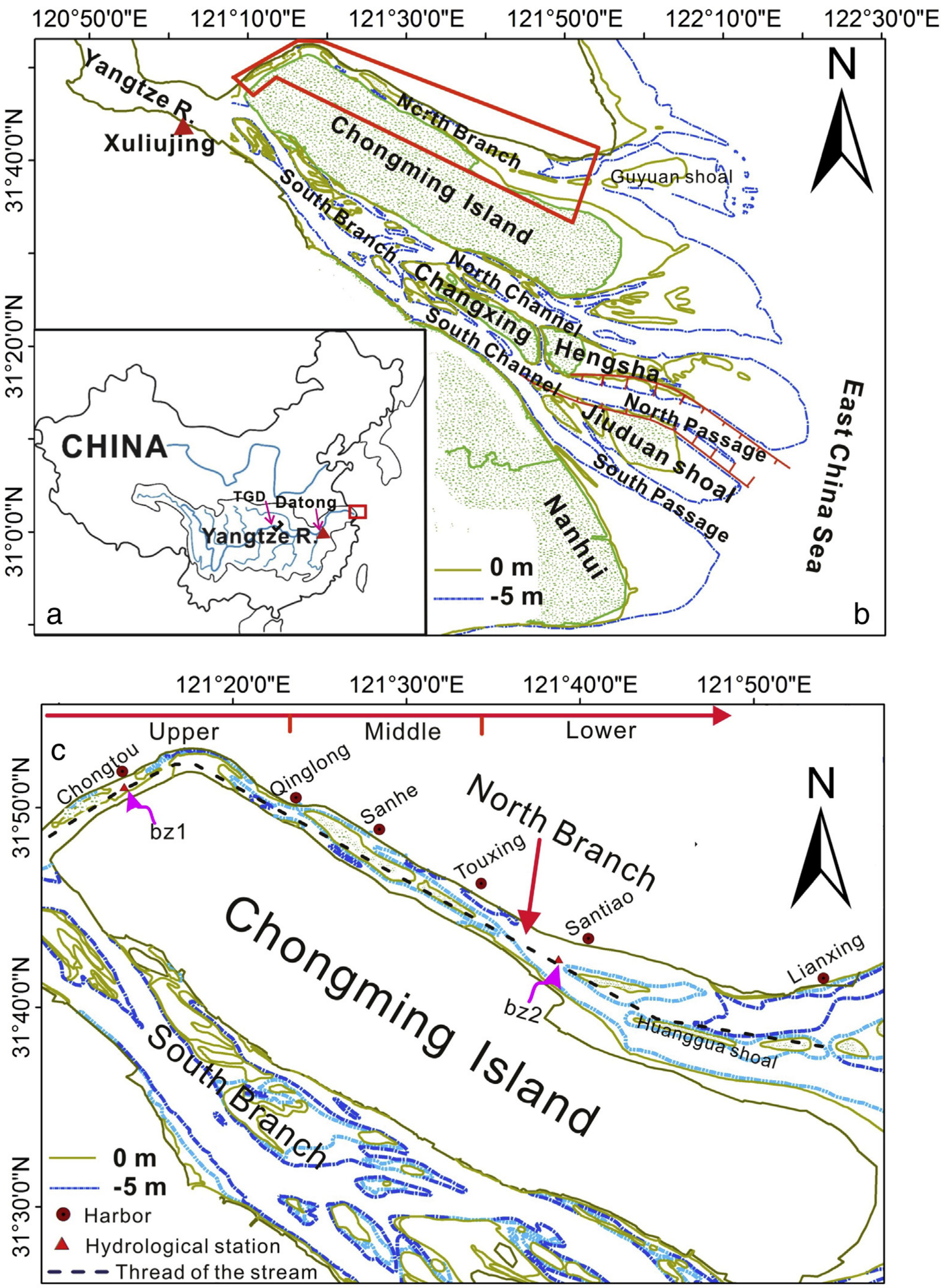

Fig. 1. Research area and location of survey stations. a: location of the Yangtze watershed in China; b: the four branches of the Changjiang estuary; c: the North Branch and associated hydrological stations.