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Sedimentary impacts of anthropogenic alterations on the Yeongsan Estuary, South Korea

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ABSTRACT

Over the last half-century, coastal zones within the Republic of Korea (S. Korea) have experienced a wide range of engineered coastal modifications including construction of seawalls, extensive land reclamation, and installation of estuarine dams. The Yeongsan Estuary has experienced all of these modifications and provides an ideal case study on how sedimentation changes within a macrotidal estuary in response to these alterations. Combined, these alterations have considerably modulated the timing and intensity of river discharge, prevented natural tidal exchange, modified the shoreline profile, and altered the transport of sediment and organic matter within the coastal zone. These impacts have been investigated using 30 gravity cores analyzed for ^{210}Pb radioisotope geochronology, laser diffraction particle size analyses, δ^{13}C and δ^{15}N isotope ratio mass spectrometry, and X-radiography. Average sediment accumulation rates range from 0.9 ± 0.6 cm yr^{-1} to 10.0 ± 2.9 cm yr^{-1}, with the highest rates proximal to the downstream side of the dam, and some areas determined to be either actively eroding or recently dredged. These results are supported by comparison of multiple bathymetric surveys, and CHIRP seismic data suggest an order of magnitude increase from average Holocene sediment accumulation rates. Side scan sonograms collected adjacent to the dam reveal distinctive scouring, transitioning to areas accumulating fine-grained sediments. Shifts in the organic matter source inputs are apparent in pre/post-dam sediments and reflect the occluding of tidal influence above the dam, resulting in increasingly terrestrial dominated signatures. Additionally, a time series of cores collected during periods of limited and high discharge analyzed for ^{7}Be, indicates sediment deposition occurs episodically corresponding to high discharge dam releases. Our observations record a shift in depositional environments as a response to an extensive array of anthropogenic alterations. Ultimately, land reclamation and dam construction have severely altered the fate and transport of sediment within the estuarine system. As a consequence, sedimentation rates have increased dramatically and depositional events are primarily controlled by discharges from the estuarine dam.
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1. Introduction

Most of the world's ports and coastal cities reside adjacent to estuaries, with approximately 65% of cities with population greater than 5 million located less than 10 m above sea level (McGranahan et al., 2007). Throughout the last century, rapid socioeconomic development has resulted in significant engineered alterations to coastal areas, and severe degradation of ecosystems (Lotze et al., 2006; Cooper, 2009; Wong et al., 2014). The industrial and urban development of estuaries has resulted in changes to shoreline configuration, fluvial discharge, tidal characteristics, and sediment dynamics (Byun et al., 2004; Crossland et al., 2005; Syvitski et al., 2005; Walling, 2006; Cuvilliez et al., 2009; Gao et al., 2012; Jackson, 2013; Wang et al., 2013; Williams et al., 2013; Liu et al., 2014; Pye and Blott, 2014). With 37% of the world's population living within 100 km of the coast (Cohen et al., 1997), and a predicted rise in sea level of between 0.3 and 1.0 m within the next century (Church et al., 2014), it is anticipated that there will be an increase of engineered structures within estuaries globally. In order to predict the results of future anthropogenic alterations, we need to understand how systems that have already undergone comparable alterations have responded. The Republic of Korea provides an ideal natural laboratory to address such issues, because many of the watersheds and estuaries have been highly modified (Lee et al., 2011). Among the 463 estuaries identified in S. Korea, Lee et al. (2011) determined that approximately half are classified as closed estuaries due to an estuarine dam or sluice gate.

The construction of estuarine dams to impede saltwater intrusion and regulate discharge, along with vast emplacement of seawalls has considerably modified many coastal areas within the last century (Yoon and Woo, 2000; Choi et al., 2005; Yoon et al., 2007). The impacts of estuarine dams and/or reservoirs constructed in coastal zones on

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sediment deposition have been investigated in numerous studies. Sedimentation rates proximal to the Keum estuarine dam (S. Korea) were reported to have increased as much as three times (<6 cm yr^{-1} to ~20 cm yr^{-1}) due to hydrodynamic changes that resulted in a decrease in overall current velocity (Kim et al., 2006). Within the Netherlands Haringvliet Estuary, several coastal engineering projects and dam construction resulted in increased sediment volume and a decrease in the tidal prism (Tönis et al., 2002). Anthropogenic alterations to the Nakdong Estuary (S. Korea) have also led to a similar reduction in the tidal prism. Geomorphological changes due to seawall and estuarine dam construction ultimately caused a shift in classification from a tide to wave-dominated estuary, resulting in a dramatic increase in sedimentation rates below the dam and re-distribution of bottom types and associated benthic habitats (Williams et al., 2013). Additionally, several studies have documented changes in sediment transport dynamics due to coastal dam construction (Barusseau et al., 1998; Yoon et al., 2007; Gao et al., 2012; Zamora et al., 2013). Management (dredging operations, etc.) and monitoring of estuarine sediment in macrotidal systems, particularly in estuaries of Northern Europe (Mitchell and Uncles, 2013), has been addressed and the need for further sediment accumulation research is apparent.

The Yeongsan Estuary (S. Korea) is a prime example of an estuary that has undergone significant coastal construction within the last century. Built to divert and impound fresh water for agricultural practices, impede the intrusion of saltwater, and provide flood prevention, the Yeongsan Estuarine Dam was constructed in 1981. As a result, approximately 98 km^2 of total estuarine area was eliminated above the dam with the cessation of tidal exchange, creating the freshwater Yeongsan Lake (Fig. 1). Prior to occlusion, tidally influenced environments spanned approximately 63 km upstream from the dam (Lee et al., 2009). Additionally, during land reclamation projects throughout the 1980s, tidal flats were filled and 90 km of seawalls/embankments were added. With a current reservoir area of 34.3 km^2, the reduction in intertidal area above the dam is estimated to be 63.2 km^2 (65%). Below the dam, land reclamation projects have reduced intertidal zones by 16.5 km^2, resulting in a total reduction of nearly 80 km^2. Seawalls have also been constructed in the region south of the Yeongsan Estuary including the Youngam seawall in 1991, and the Keumho seawall in 1994, eliminating an additional 130 and 60 km^2 of intertidal zones respectively (Kang, 1999).

Several studies have been conducted on the Yeongsan Estuary and Lake examining the changes in tidal characteristics, water structure/mixing, and biogeochemistry. In a multidisciplinary study of Yeongsan Lake, Lee et al. (2009) showed significant anthropogenic organic compound loading and oxygen depletion due to thermal and haline stratification, a reduction in fish diversity, and an increase in sediment deposition based on bathymetric change analyses. Through observational data and numerical analysis, Kang (1999) reported an increase

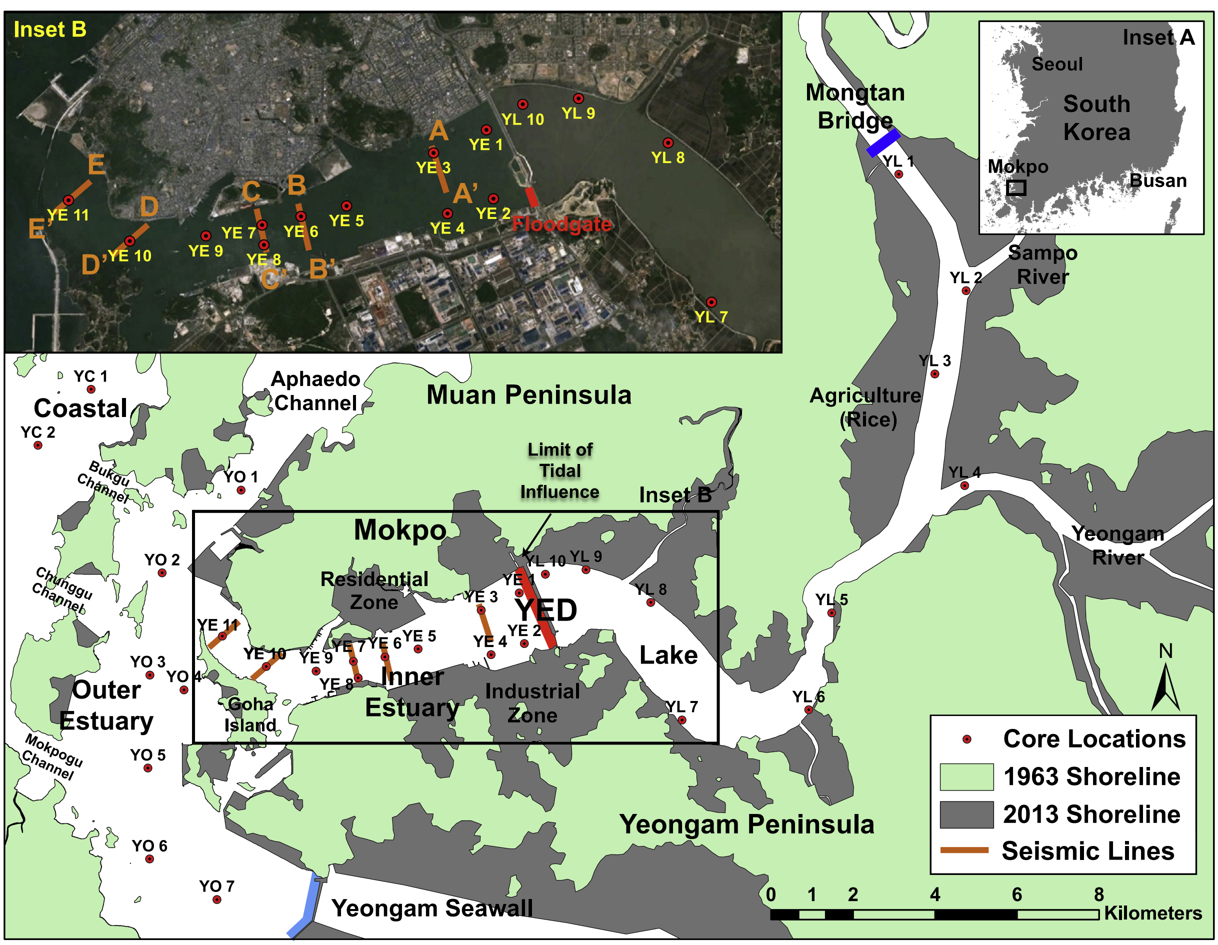

Fig 1. Detailed study area map showing location of the Yeongsan Estuary within South Korea and all core sampling locations. Inset A identifies study location within South Korea. Detailed location of cores proximal to the Yeongsan Estuarine Dam (YED) is shown within Inset B (extent has been outlined). The location of discharge release at the floodgates has been indicated within Inset B. Cores are labeled according to respective environments, including Yeongsan Lake (YL 1–10), Inner Estuary (YE 1–11), Outer Estuary (YO 1–7), and Coastal (YC 1–2) cores. The total reclaimed area is represented by the change in shoreline pre-development (1963) to the current configuration (2013), such that the difference in area represents reclaimed intertidal zones (gray zones).

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