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Combined ecohydrological effects of wind regime change and land reclamation on a tidal marsh in semi-enclosed bay

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ABSTRACT

Tidal marshes are sensitive and vulnerable to changes in the estuarine circulation. Various anthropogenic and climatic changes challenge the stability and fate of tidal marshes and introduce complicated management problems. Although the wind plays a key role in governing estuarine circulation in bays, few studies have evaluated its ecohydrological effects on tidal marshes and the interactions of its effects with those of anthropogenic activities. In this study, the independent and simultaneous effects of wind regime change and land reclamation projects were evaluated at the Mai Po Tidal Marsh in the Deep Bay, Pearl River Estuary as a case study. In recent decades, the wind regime in the Pearl River Estuary led to a stronger northeast monsoon during the dry season and a stronger southwest monsoon during the wet season. The results of hydrodynamic simulation show that the change in the wind regime and reclamation altered the governing roles of tide and freshwater discharge in the bay's seasonal estuarine circulation. The reclamation projects in the bay enhanced the effects of the stronger southwest monsoon in accelerating the estuarine circulation during the wet season, but reversed the effects of the stronger northeast monsoon in inhibiting the estuarine circulation during the dry season. Benthic infauna were used as an ecological indicator to assess the stability of the estuarine ecosystem. The predicted spatial averaged biomass of benthic infauna in the tidal marsh increased by 2% annually with the wind regime change but decreased by 28% with the reclamation; these trends were consistent with field observations. Although the change in the wind regime led to a direct reduction in the hydrodynamic disturbance in the tidal marsh and contributed to ecosystem stability, it may have shifted the hydrodynamics from sediment deposition to an erosion environment in the tidal marsh during the dry season, threatening the long-term fate of the tidal marsh.

1. Introduction

Tidal marshes are among the most economically important ecosystems on Earth because they provide a critical habitat for wildlife, play a key role in the marine aquatic food web, and contribute valuable ecosystem services to the global ecosystem and human society (Barbier et al., 2011). However, the tidal marsh ecosystem is vulnerable and sensitive to a wide range of anthropogenic and climate change effects (Kirwan and Megonigal, 2013). The hydrodynamic changes induced by coastal engineering projects and climate change are important physical forces that alter the ecosystem services of tidal marshes (Kirwan and Megonigal, 2013; Lovelock and Ellison, 2007). Ecohydrological modeling studies are therefore crucial to enhancing our understanding of the fate and stability of tidal marshes with various anthropogenic and climate change effects for environmental planning and management.

Various ecohydrological studies in tidal marshes have demonstrated strong relationships between hydrodynamic indicators (i.e., tidal current velocity, salinity, water depth, inundation period) and tidal marsh productivity (Cefalì et al., 2016; Habdija et al., 2004; Lui et al., 2002; Philippe et al., 2016; Schonberg et al., 2014; Sousa et al., 2008; Ysebaert et al., 2003). Recently, hydrodynamic indicators have been successfully used in ecohydrological models to predict ecological dynamics and to evaluate the effects of anthropogenic activities. Cozzoli et al. (2017) employed the hydrodynamic indicators of tidal current velocity and inundation period to assess the effects of coastal engineering projects on the benthic community associated with hydrodynamic changes. Yang et al. (2018) used water age and salinity to predict the temporal dynamics of the intertidal benthic infauna biomass and evaluated the disturbance caused by land reclamation projects on the temporal dynamics of the benthos.

Wind is a meteorological factor that plays a critical role in the circulation of materials in estuarine regions (Yin et al., 2004). Wind

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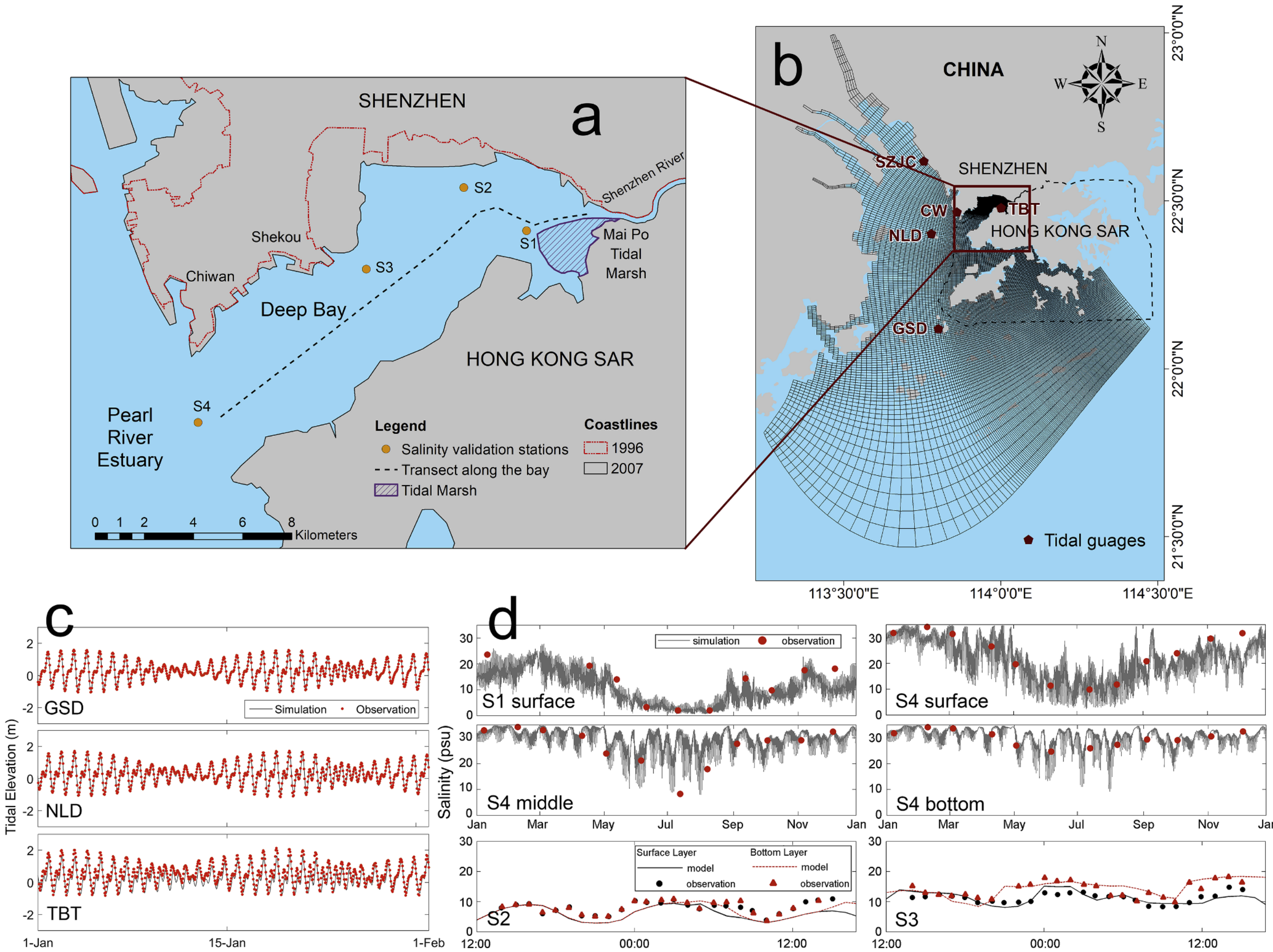

Fig. 1. (a) Map of the Mai Po Tidal Marsh and Deep Bay with coastlines in 1996 and 2007. (b) Horizontal computational grids of the numerical model. (c) Tidal elevation validation at stations in the Pearl River Estuary, whose locations are shown in b. (d) Salinity validation at various depths of stations in Deep Bay, whose locations are shown in a.

mediates the release of dissolved organic materials from tidal marshes by controlling the estuarine circulation process (Clark et al., 2017; Kuang et al., 2011). Various studies have indicated that estuarine circulation and hydrodynamics in bays are very sensitive to changes in wind forces (Talke and Stacey, 2008; Li et al., 2017), and the morphology of tidal marshes in bays may even be altered by changes in the wind regime (Callaghan et al., 2010; Statham, 2012). The primary productivity in estuarine regions is also governed by wind via estuarine circulation control (Qiu et al., 2010; Yin et al., 2004). Extreme wind events such as typhoons result in serious phytoplankton blooms in estuaries (Zhao et al., 2009). However, few studies have provided insights into the mechanism that underlies the wind-induced hydroecological effects in the coastal ecosystem. This study proposes a model of the effects of changes in the wind regime on the aero-hydroecologic dynamics in a semi-enclosed bay.

Land reclamation is one of the most economical solutions to the population explosion in rapidly developing coastal regions (Wang et al., 2014). The Netherlands has engaged in coastal reclamation for 800 years and has reclaimed approximately one-fourth of its territory from the sea (Hoeksema, 2007), and reclamation projects in Japan and China have created more than 120,000 and 13,380 km^2 of land, respectively (Suzuki, 2003; Wang et al., 2014). Reclamation, however, has become a significant threat to tidal marsh ecosystems in Europe and Asia (Cui et al., 2016). Many hydrodynamic studies have demonstrated that reclamation projects in bays would substantially alter the estuarine circulation (Gao et al., 2014; Liang et al., 2015; Okada et al., 2011; Shi et al., 2011; Yang and Chui, 2017b). Yang and Chui (2017a) used numerical models to simulate the combined effects of sea-level rise and reclamation, and concluded that the hydrodynamic effects of sea-level rise were altered by reclamation projects and would introduce various ecological effects. More recently, Yang et al. (2018) used an ecohydrological model to estimate the ecological effects associated with the hydrodynamic changes induced by reclamation projects in a semi-enclosed bay, the Deep Bay (DB), Pearl River Estuary (PRE), China. A reclamation that reduced 14% of the original water surface area of the bay would introduce a loss of about 20% in the benthic infauna biomass in the tidal marsh. A Ramsar Site inside DB hosts a great number of migratory birds each year. Thus, it is of international importance to investigate whether the hydrodynamic effects of changes in the wind regime would be altered by reclamation projects, introduce various ecological effects, and stress the stability of the ecosystem in DB.

Kirwan et al. (2016) reviewed the current threats faced by tidal marshes worldwide, highlighted the role of human effects in altering climatic effects, and suggested that an examination of the combined climatic and anthropogenic effects on tidal marshes is greatly needed. The aims of this study were (1) to examine the seasonal estuarine circulation properties with various wind regimes, (2) to identify whether and how reclamation projects would alter the hydrodynamic effects of wind regime changes, (3) to assess the independent and combined ecological effects of wind regime changes and reclamation projects, (4) to reveal the mechanism that underlies the aero-hydro-ecological dynamics in a tidal marsh inside a semi-enclosed bay, and (5) to predict