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Investigating marsh sediment dynamics and its driving factors in Yellow River delta for wetland restoration

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ABSTRACT

The wetlands of the Yellow River delta play important roles for Asian and west Pacific birds during migration. Marshes are the main component of wetlands in the delta, and their coverage area has experienced a decreasing trend for the last few decades. Wetland changes in the Yellow River delta have been analyzed in previous studies; however, those studies only partially analyzed the causes of the decline. Using statistical and spatial analysis based on observational data and remote sensing imagery for the period of 1986–2005, we found that the annual mean temperature and annual precipitation tended to increase, and the evapotranspiration and the moisture index tended to decrease. Consequently, these climate factors led to a significant decrease in river runoff, which resulted in decreased water supply for the marshes in the delta. A Wetland Restoration Project was launched in 1992, and it successfully conserved marshes within a relatively small area. However, the inadequate water supply still resulted in an overall decrease in marsh area over the entire study area. These results provide more insights into managing wetlands eco-restoration.

1. Introduction

The wetlands of the Yellow River delta represent one of the most important transfer stations for Asian and west Pacific birds during migration. Many migratory bird species such as red-crowned cranes, storks, white-spoonbills, geese, and ducks stop to replenish their foods and energy in the wetlands of the delta, then fly to other Asian and western Pacific areas (Cui et al., 2009a; Li et al., 2011; Wang et al., 2014; Liu et al., 2015). Wetlands in the area are mainly composed of marshes. However, the area of marshes has decreased due to climate change and human activities in recent decades. Engineering projects could affect the status of eco-systems (Shao et al., 2012a,b, 2015; Shao, 2014; Xu et al., 2013; Verhoeven, 2014; Joyce, 2014; Postila et al., 2015). Some engineering projects have successfully improved the wetland functions, but some failed. The main reason is that whether the managers could understand the mechanisms of changes before launching those projects. Therefore, we conducted this study for the driving changes in the marsh in order to find solutions that may lead to conservation and eco-restoration of marshes in the delta.

Marshes are covered by saturated soils and standing water during certain periods of the year. Therefore, maintaining water balance in the marsh is the key to conserving existing marsh coverage (Zhang and Shao, 2013). Precipitation, evapotranspiration, and runoff are the main factors that affect the marsh water balance. In addition, sediment discharge and human activity also play important roles in changes in marsh coverage.

Wetland changes in Yellow River delta have been analyzed in previous studies (Ye et al., 2004; Li et al., 2009; Wang et al., 2012; Chen et al., 2016). However, those studies only partially analyzed the causes of decline in marsh area. Cui et al. (2009a,b) demonstrated that maintaining adequate water is vital to sustaining wetland ecosystems; however, the interaction among precipitation, evapotranspiration, riverine water supplies, and marsh

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dynamics were not analyzed (Cui et al., 2009b; Zhang et al., 2011a,b). Therefore, the purpose of this study was to analyze the role of precipitation, evapotranspiration, river water supply, sediment load, and human activity in the marsh dynamics of the Yellow River delta for providing detailed principles for wetland eco-restoration.

2. Study area

The Yellow River delta is located on the estuary of the Yellow River near Dongying City, northeastern Shandong Province, China. Our study area was composed of the Yellow River Delta Nature Reserve and its surrounding areas, with an area of 284,260 ha. Sediment deposited from the Loess Plateau is continually expanding the delta, making the Yellow River delta a typical integrated marsh ecosystem. Elevation in our study area ranges from 0 to 37 m above sea level. Climate in this area is controlled by Asian monsoon systems. Summer is warm and wet, while winter is cold and dry.

The Yellow River Delta Nature Reserve was established in 1992, and is one of 13 key protected marshes of the world according to United Nations Environment Programme (Gao et al., 2010; Huang et al., 2012). It is composed of two separate parts: the Diaokouhe Nature Reserve and the Yellow River Mouth Nature Reserve. The current Yellow River course lies in the Yellow River Mouth Nature Reserve, and the old course is within the Diaokouhe Nature Reserve. Farmlands, oil fields, marshes, meadows, and residential areas are the main land use types in the Yellow River delta (Fig. 1).

3. Data and methodology

3.1. Data sources

Three datasets were used to analyze the interaction among precipitation, evapotranspiration, river runoff, sediment discharge, and changes in marsh coverage area. Runoff and evapotranspiration data were derived from observed data. The observed data used in our study included daily runoff, daily maximum and minimum temperature, daily precipitation, wind velocity, actual water vapor pressure, runoff, and sediment discharge from 1986 to 2005. Runoff and sediment load data were collected from the Yellow River Conservancy Commission of the Ministry of Water Resource (www.yellowriver.gov.cn). Weather data were obtained from the Dongying weather observation station and recorded by the State Meteorological Bureau. River and marsh data were interpreted from Thematic Mapper (TM) images for 1986, 1992, and 2005 downloaded from the United States Geological Survey (USGS) (www.usgs.gov). An administrative map of the Yellow River Delta Nature Reserve was obtained from local government agency and digitalized by the research team.

3.2. Methodology

The evapotranspiration at Dongying station for each year was obtained by calculating daily evapotranspiration according to the improved Penman–Monteith equation (Eqs. (1)–(7)) (Allen et al., 1998):

$$\mathrm{PET} = \frac{0.408\Delta(R_n - G) + r(900/(T+273))U_2(e_s - e_a)}{\Delta + r(1 + 0.34U_2)} \tag{1}$$

$$R_n = R_{ns} - R_{nl} \tag{2}$$

$$R_{ns} = (1-\alpha)R_s \tag{3}$$

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \tag{4}$$

$$R_a = F_{(G_{sc},d_r,\delta,\varphi,J,L_m)} \tag{5}$$

$$R_{nl} = F_{(T_{\max},T_{\min},e_a,R_s)} \tag{6}$$

where PET is potential evapotranspiration (mm d^{-1}), R_n is net canopy radiation (MJ m^{-2} d^{-1}), G is soil heat flux (MJ m^{-2} d^{-1}), T is air temperature at 2-m height (°C), U_2 is wind velocity at 2-m height (m s^{-1}), e_a is actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure curve (kPa °C^{-1}), r is the psychrometer constant (kPa °C^{-1}), and MI represents the moisture index. The values of T, U_2, and e_a were obtained from daily weather station data. R_{ns} is net shortwave radiation (MJ m^{-2} day^{-1}); α is Albedo R_s is shortwave radiation (MJ m^{-2} day^{-1}); n is the actual duration of sunshine (h); N is maximum possible duration of sunshine or daylight hours; a_s and b_s are the fraction of extraterrestrial radiation

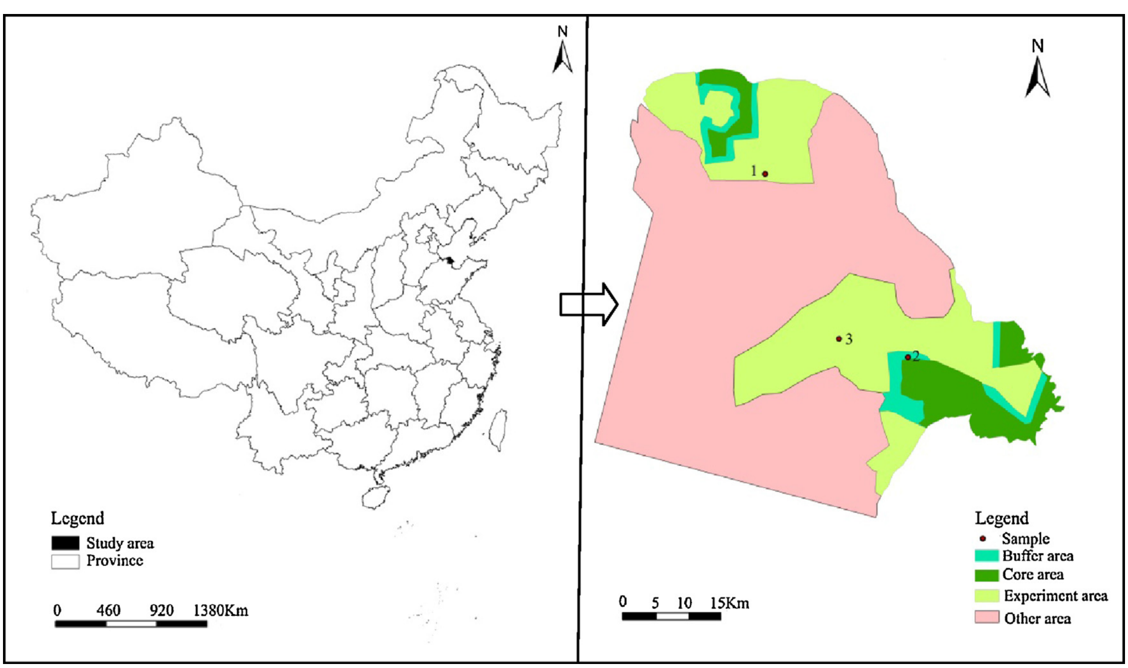

Fig. 1. Location of study area.