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Identifying potential restoration areas of freshwater wetlands in a river delta

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ABSTRACT

Identification of potential restoration areas is significant and important for implementing a sustainable restoration project and maintaining the ecosystem integrity. We established an eco-hydrological approach to identify potential restoration areas of freshwater wetlands that should and can be restored. Our eco-hydrological method identifies potential restoration areas from three dimensions, namely, transverse, longitudinal and vertical directions. Based on transfer matrix analysis between freshwater wetland and other land cover types and bird habitat suitability assessment, we identified the areas that should be restored under the 1989 and 2000 goals were 36,112 ha and 37,230 ha, respectively. Based on hydrological connectivity and balance between ecological water supply (EWS) and ecological water requirements (EWRs), the area can be restored under the 1989 and 2000 goals were 31,165 ha and 33,963 ha, respectively. The approach and results of this study can help in future restoration efforts in the Yellow River Delta and other similar coastal wetlands.

1. Introduction

The increasing value of coastal wetlands has led to a surge in interest in wetland restoration worldwide (Coats et al., 1989; Mitsch and Wang, 2000; Zhao et al., 2016). Unlike salt marshes in coastal areas, freshwater wetlands, particularly those in a river delta, are vulnerable to degradation during low inflows or periods with high sea level (Boesch et al., 1994; Stralberg et al., 2011; Wingard and Lorenz, 2014; Herbert et al., 2015; Xia et al., 2015). The success of restoration efforts depends largely on identifying appropriate areas for restoration. Given the increasing restoration initiatives for freshwater wetlands, the issue of identifying potential restoration areas, which involves questions on which area should be restored and which area can be restored, has become an important concern (Russefll et al., 1997; Strager et al., 2011; Sheldon et al., 2012).

With regard to the first question, freshwater wetlands are often restored for the return of land use/land cover (Stein et al., 2010) and habitat enhancement (Simaika and Samways, 2011), particularly habitats for waterbirds (Özesmi and Mitsch, 1997; Corre et al., 2012). With regard to the second question, several recent freshwater wetland restorations focused on the hydrological regime, including the timing, amplitude, frequency and duration of high water (Zedler, 2000; Hammersmark et al., 2005; Convertino et al., 2013). Rarely have freshwater wetland restoration projects been undertaken with the consideration of hydrological connectivity, which determines the availability of freshwater (Cabezas et al., 2008) and whether ecological water supply (EWS) can meet ecological water requirements (EWRs) (Rood et al., 2005; Erwin, 2009); hydrological connectivity and EWS are crucial in identifying areas in freshwater wetlands that can be restored.

The approaches utilized to identify potential restoration areas of freshwater wetlands have been widely investigated on the landscape scale (Simenstad et al., 2006; Maron and Cockfield, 2008; Nelson et al., 2009). From the landscape perspective, freshwater wetlands are part of the complex matrix comprising other land cover types. Measurement of the changes in land use/land cover by means of geographic information system (GIS) technology has been proved to be effective in identifying potential restoration areas (Thompson et al., 2006; Bortoleto et al., 2016). Moreover, habitat maps on the landscape scale can help identify priority areas for potential restoration (White and Fennessy, 2005; Morisette et al., 2006; Kuemmerle et al., 2011). However, the actual challenge is not only identifying the areas to be restored but also determining whether these areas can be restored; this restoration may be

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limited by hydrological connectivity and EWS. Hydrological connectivity determines the pathway of water source accessibility, and EWS determines the quality of water source accessibility. As one of the most important components of a wetland network, hydrological connectivity is usually calculated based on graph theory (Lin et al., 2009; Urban et al., 2009). EWS is a crucial component of water resources allocation and management. To calculate EWS, water balance under different scales should be considered (Xin et al., 2015).

Despite these developments, no detailed integrated approach has been presented to identify potential restoration areas, which should not only be restored, but can also be restored. Therefore, an approach for the appropriate identification of potential restoration areas for freshwater wetlands needs to be established. Such an approach should address the two aforementioned questions. We therefore present an eco-hydrological approach that is based on satellite-derived and monitoring data of the selected study area. The objective of this study is to provide a hybrid approach for the integration of ecological and hydrological indicators to identify the potential restoration areas of freshwater wetlands.

2. Material and methods

2.1. Study area

Yellow River Delta is located in the estuary of Yellow River in Dongying City of Shandong Province and at the south of Bohai Sea, China, including 3 counties (Kenli, Lijin and Hekou), which is widely recognized as having one of the highest sediment yields in the world. It has a temperate continental monsoon climate with distinct seasons and a hot rainy season. The annual mean temperature ranges from 11.5 °C to 12.4 °C, with a frost–free period lasting 196 days. As located in a semi-arid zone, the delta has an average annual precipitation and average annual evaporation, with 551.6 mm and 1962 mm, respectively. With the decrease of the annual runoff of the Yellow River and the diversion of freshwater to wetlands since the 1980s, large areas of freshwater wetlands (freshwater marshes in this study) have degraded, as manifested by the reverse succession of vegetation and serious destruction of waterbird habitat (Cui et al., 2009b). In 1991, the Yellow River Delta Natural Reserve (YRDNR) was established to protect original wetlands and improve habitat. Ranging from 37.5795°N to 38.2052°N and 118.5497°E to 119.3408°E, the total area of the YRDNR is approximately 153,000 ha, including the core, buffer and experimental area, with area of 58,000 ha, 13,000 ha and 82,000 ha, respectively. However, freshwater wetlands in the whole river delta are still suffering from degradation. In restoration ecology theory, a desirable recovery of wetland is to restore the current state to a more "natural" state that is similar to the previous state. Therefore, two scenarios of freshwater wetland restoration were established to identify potential restoration areas based on previous state of 1989 and 2000 in this study.

2.2. Data collection and processing

Before processing, we prepared the following digital data: land use mapping and multi-spectral Landsat-5 TM scenes with 7 bands; historical data (i.e., bird data and annual runoff data); and field monitoring data (i.e., vegetation characteristics, water depth, and types and habitat preferences of waterbirds).

A land use mapping of China in the scale 1:50000 and vegetation mapping were supplied by the Yellow River Delta Management Bureau. Three multi-spectral Landsat-5 TM scenes with 7 bands from dates October 3, 1989, April 8, 2000 and September 11, 2010 with 30 m ground resolution were available for the study area.

Landsat TM bands 3, 4 and 5 were selected for classification due to their spectral response to chlorophyll absorption (band 3), chlorophyll reflection (band 4) and water absorption (band 5). As the TM images have already been processed by radiometric correction and geometric correction using ground control points, we processed geometric precision correction using quadratic polynomial function and resample by bilinear interpolation to control the accuracy within 0.5 pixel. The TM images were georeferenced to a UTM-WGS 84 coordinate system.

Remote sensing classification was the main process while analyzing the remote sensing data. The images in 1989, 2000, and 2010 were interpreted by using a multi-extracting method that combined supervised classification with non-supervised classification by ENVI4.3 and ArcGIS10 software. After pre-classification, artificial visual interpretation was performed to determine the wetland classification based on field observations. We developed the Yellow River Delta classification system according to the Ramsar Convention on Wetlands of International Importance, Technical Specification for Survey and Monitoring of Wetland Resources, land use mapping, and field observations. Three systems and twelve types of landscapes were distinguished: natural systems, including permanent shallow marine waters, rivers, tidal flats, freshwater marshes, and salt marshes; manmade systems, including water storage areas, aquaculture (e.g., fish/shrimp) ponds, salt ponds, and paddy fields; systems other than wetlands, including forest land, farmlands, and construction land (e.g., road/oilfield).

Bird data between 2001 and 2011 were provided by the Yellow River Delta Management Bureau. A total of 296 species were recorded in 2011, accounting for 25% of the bird resources in China. Among the bird species, we observed 10 national first-class protective species and 49 national second-class protective species. According to historical records and previous research (Duan, 2010; Xue, 2010), *Charadriiformes*, *Anseriformes*, *Lariformes*, *Ciconiformes*, and *Gruiformes* were selected as the representative and objective birds.

Annual runoff data of Lijin Hydrological Station from 1956 to 2010 were obtained from Hydrologic Annals. Data on the water into Bohai Sea, precipitation, evaporation, and out-stream water demands from 2001 to 2010 were also collected from the statistical yearbooks of Dongying and water resource bulletins of Yellow River Basin.

Field monitoring of water depth and *P. australis*, which is the dominant plant species in the freshwater wetlands of the study area, was conducted monthly from March 2009 to October 2009. Seventy-two sampling sites at intervals of 200 m were arranged. Three 1 m × 1 m spots were set in each site. The water depth and vegetation height in each sampling spot were measured with a self-braking steel tape rule (Ref). The vegetation coverage and geographic position were also measured with a GPS (version: GARMIN eTrex Venture). The records obtained from the three sampling spots were averaged to represent the monthly characteristics of each site. Monthly data from March 2009 to May 2009, June 2009 to August 2009, and September 2009 to October 2009 were then averaged to obtain seasonal data for spring, summer, and fall, respectively. Data for winter are similar to that for fall.

2.3. Overall process

A potential restoration area of a freshwater wetland should have the following properties: (1) it was a freshwater wetland in the past, (2) the habitat is not suitable in its current state, (3) the area is within the current hydrological network, and (4) EWS for the area can meet EWRs. Only by having these four characteristics can a site be identified as a potential restoration area (Fig. 1). The potential restoration areas of freshwater wetlands were determined through transfer matrix analysis of freshwater wetlands and