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Factors driving the relationships between vegetation and soil properties in the Yellow River Delta, China

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ABSTRACT

For wetland ecological restoration, characterizing the relationship between plant communities and soil characteristics has long been recognized as a key issue. Due to the spatial variability in soil properties, multi-scale studies in the context of scale issue is necessary to reveal the complex relationship operating at different intensities. However, insufficient research focuses on the relationship between soil and vegetation at different scales in the Yellow River Delta. In our study, Canonical Correspondence Analysis and the lowest Akaike Information Criteria methods were used to investigate their inherent relationships at three scales (region, sub-region and landscape scale) in Yellow River Delta. The results showed that vegetation properties were strongly related to different variables of soil characteristics at different scales. At the region and landscape scales, soil organic matter, K^+ and SO_4^{2-} were strongly related to vegetation properties, while soil water content, NO_3^-, soil organic matter and total phosphorus were more important at sub-region scale. Additionally, we found that the soil organic matter was most strongly related to vegetation coverage at the region scale based on the result with the lowest Akaike Information Criterion. Soil nutrients and inorganic ions might be more strongly related to vegetation properties, and their correlations varied according to scale.

1. Introduction

Understanding the relationships between ecological variables in a given ecosystem has applications in management, reclamation, and development of similar regions. The relationship between vegetation and environment has been a subject of many ecological studies (Marty et al., 2017; Zhou et al., 2016; Jiang et al., 2016; Nelson et al., 2015; Breen et al., 2015). For wetlands, characterizing environmental variables that affect ecological processes has long been recognized as a key issue in plant community ecology (Lu et al., 2006).

Some of the factors that create microsites for vegetation include climate (Wang et al., 2017; Chu et al., 2016; Yu et al., 2016), topography (Chau and Chu, 2017; Alexandre et al., 2016), hydrologic conditions (Marini et al., 2008), land use (Yagoub et al., 2017), natural resource exploitation (Zhang et al., 2016; Weber et al., 2015), and in particular, soil characteristics (Lozano-García et al., 2016; Amorim and Batalha, 2007). Among different environmental factors, soil plays a fundamental role in plant growth. It is well-known that soil is a function of climate, organisms, topography, parent material, and time (Bruelheide and Udelhoven, 2005; Jafari et al., 2004; Ferraro and Ghersa, 2007).

Vegetation characteristics are affected by a variety of factors, among these factors, the soil properties are an essential component that influences vegetation. The relationships between vegetation characteristics and soil properties are complicated at different scales in respect to the distribution of plant species and vegetation heterogeneity. It is significant to determine the relationships to understand ecosystem processes (Shen et al., 2016; Fu et al., 2004). Therefore, soil was selected as the environmental factor related to vegetation properties in our research. As one of the fastest-growing estuarine deltas in China, perhaps even in the world, the Yellow River Delta has unique soil-vegetation interactions that are important to study. So far, there have been limited reports on issues related to this area. At large scale, there has been a focus on the relationships between coastal meadow distribution, soil characteristics, and between typical vegetation. Soil salinity, and groundwater depth were also determined for the entire Yellow River Delta (Tan et al., 2012; Ma et al., 2013). At small scale, Guan et al. (2014) revealed the ecological characteristics of *Phragmites australis* vegetation at different water table levels and their relation to environmental factors in a Nature Reserve of Yellow River Delta. Zeng

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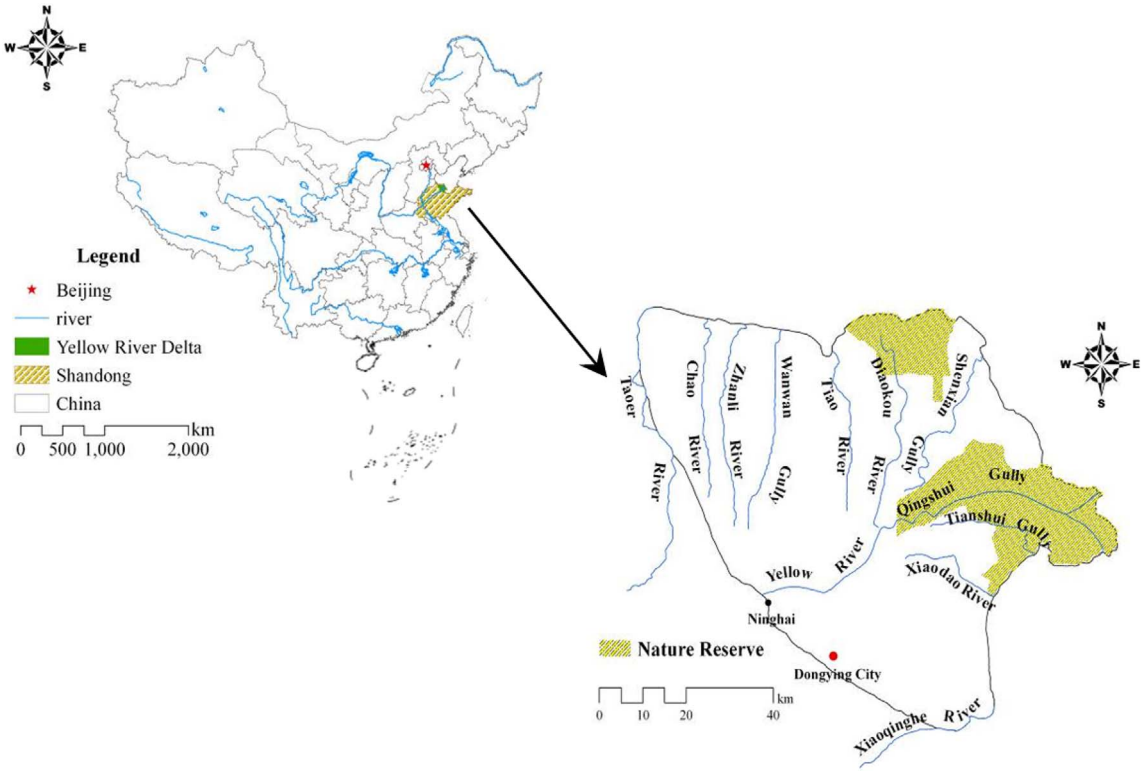

Fig. 1. Location of the Yellow River Delta.

and Zhang (2016) found that the relationship between soil distribution and plant heavy metals in this area. However, these studies did not consider the difference between vegetation and environmental factors at different scales. Since the scale is dependent on soil nutrient, water content, and other resource variations, the vegetation characteristics dominated by these factors could have diverse results at different scales (Lindo and Winchester, 2008; Liu et al., 2007). The main objectives of this research were to identify the relationships between vegetation properties and soil characteristics at three different scales.

2. Materials and methods

2.1. The study area

The study was carried out in the Yellow River Delta, which is located at 37°20′-38°12′N, 118°07′-119°10′E occupying an area of more than 6000 km^2 (Fig. 1). Its boundary starts from Ninghai, and extends northeast to the Taoer River estuary, southeast to the Xiaoqinghe River estuary, and eastward as a fan shape area. The research site is located in northern Shandong Province, China (Fig. 1), of which the newly created wetland extends from the mouth of the Yellow River to the Bohai Sea. The current course of the Yellow River was artificially formed by changing the old course from Diaokou River to Qingshui gully in 1976. Due to the deposition of large amounts of sand and mud transported by the Yellow River together with lateral sea seepage, soils in the delta are formed from marine sediments (Liu, 2007). The Yellow River Delta is characterized by extensive coverage of saline soils, a high proportion of which, occurs in the most actively propagating areas in conjunction with recently formed estuarine wetlands.

The study area has a monsoon climate and is based in a warm-temperate zone (Zhao and Song, 1995). The average annual temperature is 11.7 to 12.6 °C. The average annual precipitation is 530 to 630 mm, of which 70% is rainfall during summer (May–July), and the ratio of evaporation to precipitation is an annual average of 3.22. The groundwater table in the delta is generally high, ranging from 1.6 to 2.4 m, with on average a mineralization degree of 32.4 $g\,L^{-1}$. The natural vegetation in the area is most commonly based on salt-tolerant herbaceous plants and shrub components, especially coastal saline or salt-tolerant meadow vegetation. The dominant species include *Suaeda glauca (Bunge) Bunge.*, *Suaeda salsa (L.) Pall.*, *Tamarix chinensis Lour.*, *Tamarix ramossisima Ledeb.*, *Apocynum venetum L.*, *Phragmites australis Trin.*, *Aeluropus sinensis (Debeaux) Tzvel.*, *Limonium sinense (Girard.) Kuntze*, *Artemisia capillaries*, *Scorzonera mongolica Maxim.*, and *Artemisia fauriei Nakai* (Ma et al., 2013).

2.2. Data collection

Field surveys were under-taken at three different regional scales; scales—regional area (the entire Yellow River Delta, 6000 km^2), sub-regional area (Dawenliu Nature Reserve, ~400 km^2) and landscape scale (Square quadrants in the core area of Dawenliui Nature Reserve, 1 km^2), (Fig. 2), corresponding to the three scales in our study.

2.2.1. Vegetation data

A total of one hundred and five plots were collected over the nested areas, 36 plots at the regional scale, 33 at the sub-regional scale and 36 at landscape scale, respectively (Fig. 2). In each plot, three quadrats were randomly selected. The geographical coordinates of plot center position were recorded using a hand-held GPS locator. The vegetation type, coverage, plant height, and number of plants were surveyed within three randomly distributed 1 m × 1 m quadrats in each plot. Vegetation coverage was determined by visual method according to the vegetation vertical projection area as a percentage of the quadrat area. For the above ground biomass, plants were collected only in the aboveground part for each plot, weighing fresh mass immediately, then the fresh materials were weighed immediately and put into the sealed bag, labeled, and brought back to the laboratory. In the laboratory, the fresh plant samples were dried in a constant temperature oven at 80 °C for 8 h and then weighed out. These plants were multiple baked in a drying oven for 4 h and then weighed once again until the error