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Original Articles

Salt marsh vegetation distribution patterns along groundwater table and salinity gradients in yellow river estuary under the influence of land reclamation

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ABSTRACT

Estuary protection is a fundamental part of watershed management. However, land reclamation activities affect species distribution patterns and cause ecological degradation. To improve watershed management, we studied the distribution patterns of three typical salt marsh species and their interspecific interactions along groundwater table depth and salinity gradients using an index of Field Box Dimension and a Relative Interaction Index. We also simulated the groundwater gradient after two typical land reclamation activities, sea reclamation and embanking, after ten years. Our results showed that sea reclamation will change the location of the groundwater salinity peak along a land-to-sea transect and that there is no salinity peak after embanking. Vegetation distribution patterns also differed, from a zonal pattern (in salt marsh) to a mosaic pattern (after embanking). The decrease in the salinity gradient of the non-core area is an important cause for the differences we found in vegetation patterns.

1. Introduction

Estuarine wetland protection is a crucial part of watershed management. Construction projects (e.g. sea reclamation, embanking) change interactions between land and sea, causing the biotic and abiotic factors to change, leading in turn to changes in vegetation distribution patterns. Salt marsh vegetation often exhibit predictable patterns of zonation along an environmental gradient caused by the interaction of land and sea (Xin and Jin, 2008; Xin et al., 2009; Xin et al., 2010; Marani et al., 2013). A wide range of biotic and abiotic factors influence ecological zonation.

Abiotic factors linked to salt marsh zonation include soil moisture content, redox state, nutrient limitation, and salinity (Silvestri et al., 2005; Moffett et al., 2012). There has also been a broad discussion on the relationship between vegetation and soil factors (He et al., 2009). Silvestri et al. (2005) found that hydrogeologic factors were also important regulators of plant zonation patterns in estuarine and coastal areas. Wilson et al. (2015) examined groundwater flow patterns through surficial sediments in two salt marshes in the southeastern United States to analyze the relationship between groundwater and vegetation distribution. Antonellini and Mollema's (2010) study showed that the growth of salt marsh vegetation was influenced by groundwater table depth and salinity. Higher groundwater tables and lower groundwater salinities were related to higher the species richness and diversity.

Interspecific interaction is an important factor driving vegetation distribution in estuarine areas (Crain, 2008; Qi et al., 2016). However, interspecific interaction is influenced by abiotic factors to a large extent. Therefore, abiotic factors are the initial and primary causes that drive variations in vegetation distributions (He et al., 2012).

Large-scale human alterations, such as land reclamation, have been impacting ecosystems of coastal zones for a long time (Zhu and Xu, 2011). Land reclamation in coastal areas have had a significant effect on local groundwater systems (Guo and Jiao, 2007). After reclamation, the water table rises and the saltwater/freshwater interface moves seaward (Guo and Jiao, 2007; Hu and Jiao, 2010). Embanking, a typical land reclamation activity that uses dikes (embankments) to prevent sea water from reaching the land protected behind the dikes. Although embanking changes the groundwater gradient, embankment cannot prevent groundwater exchange. Salt water can still upwell into the embanked land in groundwater and the saltwater/freshwater mixing zone becomes narrower. This narrowing causes interspecific interactions among vegetation to change relative to changes in the groundwater gradient. Vegetation distribution patterns change in response to changing aboitic and biotic factors (Crain et al., 2004). However, few studies have discussed the relationship between vegetation distribution

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patterns and groundwater when studying land reclamation activities. These factors are poorly understood and are often neglected when protecting coastal wetlands and planning watershed management stategies.

This study analyzed the characteristics of three typical salt marsh plant species using Field Box Dimension and a Relative Interaction Index, and simulated variations of groundwater gradients after sea reclamation and embanking in a coastal area. We also studied soil salinity, groundwater table depth, and salinity gradients during several months at our study sites. We discussed the relationship between vegetation and groundwater gradients. Our hypotheses were: (1) the vegetation zonal distribution pattern will become narrower after embanking and (2) the groundwater gradient is an important factor driving the distribution of vegetation. This study will contribute to the understanding of the interaction between "pattern and process" in the landscape ecology of coastal zones and provide a scientific basis for the management of coastal watersheds.

2. Site description

The study area is located at the Yellow River Delta, located in the northern part of Shandong Province, China (Fig. 1). It lies on the southern side of the Bohai Sea, spanning from 118°08′07″ E to 119°08′18″ E, and from 36°55′ N to 38°12′ N, covering an area of approximately 6010 km^2. The region of the Yellow River Delta is characterized by a temperate, semi-humid, continental, monsoon climate. The average annual temperature is 11.7–12.6 °C. Average annual precipitation is 530–630 mm, of which 70% occurs as summer rainfall (May–July) (Yu et al., 2013).

Significant amounts of sediment are carried by Yellow River and are deposited at the river mouth, forming new land. Even as new land forms, sea water intrusion also continuously erodes other coastal areas. An average water table, ranging from 0.2 m to 3.0 m, has been observed in the last two decades (Li et al., 2008). Dominant species in the Yellow River Estuary inlcude *Phragmites australis* (*P. australis*), *Triarrhena sacchariflora*, *Tamarix chinensis*(*T.chinensis*), *Suaeda salsa*(*S. salsa*), and *Limoninum sinense* (He et al., 2008; Qi et al., 2016).

3. Methods

3.1. Field sampling

We established each transect either entirely in a natural estuarine area or in an embanked area. In order to compare soil salinity,

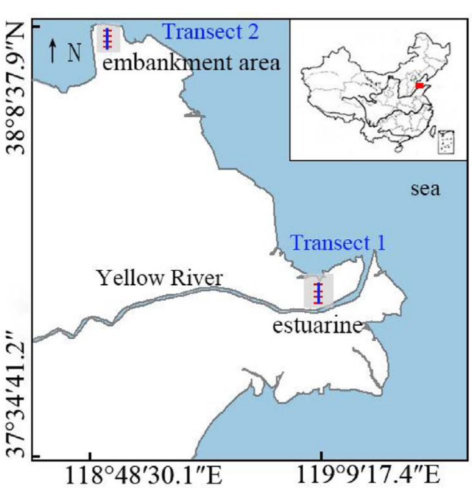

Fig. 1. Study sites in the Yellow River Delta, northern China. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

groundwater table, groundwater salinity, and vegetation distribution patterns between the embanked and estuarine areas, we determined that the areas for transects should satisfy certain conditions. In the estuarine area, the transect should: (1) be without (or almost without) human alteration and (2) support vegetation that is distributed zonally, the pattern typical of coastal wetlands in the region. In contrast, for the embanked area, transects should: (1) be where seawater is prevented from intruding onto land via tidal action or storm surge, (2) be in an area converted to land at least 8 yr prior to sampling, so that vegetation distribution patterns would have likely stabilized, (3) be located in an area that is covered with plants, and (4) have a landuse was not a salt field or aquacultural farm.

In Transect 1 (3800 m, located in the natural estuarine area), the distance between adjacent monitoring wells was about 150 m, so there were 15 monitoring wells in Transect 1 (Figs. 1 and 2). Due to lack of an adequate power supply for our drilling equipment, there were only seven monitoring wells placed in Transect 2 (3500 m, located in the embanked area). These monitoring wells were sampled for groundwater salinity. The groundwater table of these monitoring wells was continuously recorded with several capacitance water level recorders.

We collected five soil samples (5.05-cm diameter, 20-cm depth) in both transects around each well in different months. Soil cores were oven-dried, and after drying, the soil was mixed with a known volume of deionized water (the mass ratio of dried soil and water was 1:5). The salinity of the supernatant was measured after 24 h using an electronic meter (Pennings et al., 2005). We sampled vegetation in four sites (locations) along each transect. Vegetation at each site was quantified in May 2016 by randomly sampling three 5-by-5-m quadrats in each habitat-type at each location and visually estimating percent cover for each of three species: *S. salsa*, *T. chinensis*, and *P. australis*.

3.2. Analyzing vegetation distribution characteristics

We employed the Field Box Dimension (D) to measure the space competitiveness (Sugihara and May 1990). The larger the box dimension of the species, the greater is its space competitiveness. Box dimension quantifies the space occupied by plants and the complexity of plant distribution patterns. The equation follows:

$$\lg N(\varepsilon) = -D\lg\varepsilon + A \tag{1}$$

where, N is the number of boxes within which the species grows, ε is the side length of each individual square box, A is a constant.

A single plant of *S. salsa* and *P. australis* occupies a much smaller area than a single plant of *T. chinensis*, and so the dimensions of its boxes would therefore differ between these plant species. For *T. chinensis*, the side length of boxes were 1.2 m, 2 m, 3 m, 5 m, 6 m, 10 m, 15 m, 20 m and 30 m, while for *P. australis* and *S. salsa*, boxes lengths were 0.5 m, 1 m, 2 m, 2.5 m, 5 m, and 10 m.

We used the Relative Interaction Index (*RII*) to represent the relative interaction intensity among plants. Armas et al. (2004) introduced the *RII* to measure the relative interaction intensity of plants and proved it can be applied to any kind of interaction (from competitive exclusion to symbiosis). *RII* has defined limits [-1, 1], has identical absolute values for competition and facilitation, is linear, and does not have discontinuities in its range. *RII* is therefore safe to use in statistical and mathematical operations. *RII* distribution is approximately normal, with means equal to the true population mean and a sampling variance that can be derived. *RII* uses basic arithmetical operators, and it can be scaled up and used to measure multispecific interactions at the community level (Armas et al., 2004).

Since *P. australis* and *T. chinensis* did not occur at all the sites and *S. salsa* occurred at all sites in both areas, we only analyzed the *RII* of *S. salsa*. The following equation defined *RII*:

$$RII = (B_W - B_0)/(B_W + B_0) \tag{2}$$

where, under natural conditions, B_w is the biomass when growing with