# Spatial Distribution Characteristics of Vegetation in the Yellow River Delta and Their Environmental Interpretation: Postprint

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## Abstract

To understand the relationship between vegetation spatial distribution and environmental factors in the Yellow River Delta region, we conducted local vegetation quadrat surveys, extracted Normalized Difference Vegetation Index (NDVI) from regional remote sensing imagery, and collected environmental data including terrain elevation, groundwater depth, and surface soil $Cl^-$ content. Integrated plot vegetation and environmental data were subjected to Detrended Correspondence Analysis (DCA) and Detrended Canonical Correspondence Analysis (DCCA), and single-factor correlation analysis and multiple stepwise regression analysis were performed between regional NDVI and major environmental variables. The results indicated that DCA ordination could classify the vegetation of the Yellow River Delta into four main community types (associations): *Suaeda salsa*, *Tamarix-Suaeda salsa*, *Phragmites australis-Tamarix*, and *Phragmites australis*. While the DCCA ordination diagram was generally similar to that of DCA, DCCA more clearly revealed that its first axis primarily represented key water-salt factors such as phreatic $Cl^-$ concentration, and that communities gradually evolved from *Suaeda salsa* to *Phragmites australis* with decreasing salt content in the soil-water environmental system. The distribution patterns and variation trends of regional typical vegetation communities and NDVI were significantly influenced by two environmental factors—groundwater depth and phreatic $Cl^-$ concentration (the binary regression equation established between NDVI and these two environmental variables yielded $R^2 = 0.57$), while the vegetation effect of soil $Cl^-$ content was actually mediated by groundwater depth and phreatic $Cl^-$ concentration. Under conditions of shallow groundwater throughout the region, groundwater became the most sensitive ecological environmental element affecting vegetation growth and distribution, with groundwater depth and phreatic $Cl^-$ concentration serving as the two key factors within this element; particularly, the gradient variation of the latter

exerted an important controlling effect on the distribution pattern of natural vegetation.

## Full Text

## Spatial Distribution of Vegetation and Environmental Interpretation in the Yellow River Delta

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### Abstract

To understand the relationship between vegetation spatial distribution and environmental factors in the Yellow River Delta, we conducted quadrat surveys of local vegetation, extracted the Normalized Difference Vegetation Index (NDVI) from regional remote sensing imagery, and collected environmental data including topographic elevation, groundwater depth, and chloride ion content. We performed Detrended Correspondence Analysis (DCA) and Detrended Canonical Correspondence Analysis (DCCA) integrating vegetation and environmental data, and conducted single-factor correlation analysis and multiple stepwise regression analysis between NDVI and major environmental variables. The results showed that vegetation in the Yellow River Delta could be divided into four main community types: *Suaeda heteroptera*, *Tamarix chinensis*, *S. heteroptera*-*T. chinensis* mixed, and *Phragmites australis*. While DCCA and DCA ordination diagrams were generally similar, DCCA more clearly revealed that the first axis primarily represented chloride concentration in the phreatic aquifer and key water-salt factors. As salinity in the groundwater-soil environmental system decreased, communities evolved from *S. heteroptera* toward *P. australis*. The distribution of vegetation communities and NDVI in the study area was significantly influenced by groundwater depth and chloride concentration in the phreatic aquifer. A binary regression relationship ($R^2 = 0.57$) was established between NDVI and two environmental variables. The effect of soil chloride content on vegetation was actually mediated by groundwater depth and chloride concentration in the phreatic aquifer. Under the region' s shallow groundwater conditions, groundwater became the most sensitive ecological factor affecting vegetation growth and distribution, with groundwater depth and chloride concentration being two key factors—particularly the latter, whose gradient changes exert important control over natural vegetation distribution patterns.

**Keywords:** vegetation distribution; environmental interpretation; Normalized Difference Vegetation Index (NDVI); vegetation ordination analysis; Yellow River Delta

## Introduction

The relationship between vegetation spatial distribution and environmental factors has long been a central focus in ecological research, providing scientific foundations for degraded ecosystem restoration and reconstruction. Plant community distribution is driven by multiple natural factors including climate, topography, soil, and groundwater. At broad scales, climate plays a decisive role in vegetation distribution, while at local scales, topography, soil properties, and biological interactions also influence community patterns. Gradient analysis methods in ecological statistics, including indirect gradient analysis (e.g., Detrended Correspondence Analysis, DCA) and direct gradient analysis (e.g., Canonical Correspondence Analysis, CCA and Detrended Canonical Correspondence Analysis, DCCA), can semi-quantitatively identify key small-scale environmental factors affecting plant community type changes and distribution using species composition data and measured or potential environmental variables.

Terrestrial plants, rooted in soil, are profoundly constrained by local environmental conditions, particularly soil moisture and salinity. In coastal areas, seawater intrusion and upstream tidal effects cause groundwater salinization, leading to soil degradation, biological community changes, and plant succession. Groundwater can affect soil moisture and salinity through vertical water exchange, producing ecologically significant effects that extend from point to area scales. In the Yellow River Delta, groundwater is generally shallow and highly saline, making its role in water-salt migration and vegetation distribution particularly important. Previous studies on vegetation-environment relationships in this region have focused on eastern nature reserve estuarine wetlands, emphasizing influences of surface water depth and soil nutrient content. This study integrates two perspectives—vegetation community spatial distribution based on quadrat surveys and vegetation coverage from remote sensing imagery—to comprehensively analyze ecological relationships between plant spatial distribution patterns and environmental factors, providing scientific support for rational ecological scheduling in the lower Yellow River and active maintenance of coastal wetland ecosystem health.

## 1. Data Collection and Sampling Design

The study area is bounded by the coastline to the north (118°34 –119°15 E, 37°36 –38°09 N) and extends to the western end of the northern nature reserve and southern end of the eastern nature reserve. Environmental data were collected through the 2008 Yellow River Delta Coastal Wetland Comprehensive Geological Survey and Evaluation Project, covering 27 sampling stations. Data included: NDVI extracted from remote sensing imagery, groundwater depth, chloride concentration in phreatic water, total dissolved solids (TDS) in phreatic water, surface soil chloride content, soil total salt content, soil organic matter content, pH, and synchronous records of surface cover types at each station (including *Suaeda heteroptera*, *Tamarix chinensis*, *Phragmites australis*, etc.) [Figure 1: see original paper].

In May 2008, we selected 20 survey plots (S1-S20) in the northeastern nature reserve of the Yellow River Delta. For each 50 m × 50 m plot, we recorded plant species, abundance per unit area, and other parameters.

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## 2. Data Processing and Analysis

For vegetation-environment ordination analysis, vegetation data consisted of species abundance values from 20 plots, while environmental data included topographic elevation, groundwater depth, chloride concentration and TDS in phreatic water, surface soil chloride content, organic matter content, and pH at corresponding sampling stations.

We first performed Detrended Correspondence Analysis (DCA) to determine whether to use linear or unimodal models. Considering the numerous zero values in species abundance data, we selected unimodal-based ordination methods. After screening, we used DCCA to analyze species and environmental data from 20 plots, with topographic elevation, groundwater depth, chloride concentration and TDS in phreatic water, surface soil chloride content, organic matter content, and pH as environmental variables. All ordination analyses were conducted using Canoco 4.5 software.

For regression analysis between NDVI and environmental factors, we used ENVI 4.8 to extract NDVI values and imported them into ArcGIS. Using the "Extract Values to Points" command, we extracted NDVI values for sampling stations and then performed single-factor correlation analysis and multiple stepwise regression analysis using SPSS 17.0 [12].

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## 1. Typical Vegetation and Its Spatial Distribution

The main plant species in the study area include *Phragmites australis*, *Tamarix chinensis*, *Suaeda glauca*, *Imperata cylindrica* var. *major*, *Miscanthus sacchari-*

*florus*, *Glycine soja*, *Aeluropus littoralis* var. *sinensis*, *Setaria viridis*, *Salix integra*, *Apocynum venetum*, *Typha orientalis*, and *Limonium sinense.* The nature reserve contains 393 seed plant species with approximately 55.4% vegetation coverage, among which typical vegetation types *Suaeda heteroptera*, *Tamarix chinensis*, and *Phragmites australis* are widely distributed.

Based on vegetation quadrat surveys, field sampling records, remote sensing imagery, and reference to studies by Cui Baoshan and Yang Zhifeng [13], typical vegetation is mainly distributed within protected areas. In the eastern nature reserve, vegetation forms a banded distribution along the Yellow River channel extending from the estuary upward to the Dawenliu management station (approximately 45.0 km). From the river channel outward to the high-tide line, the sequence is *P. australis*, *T. chinensis*, and *S. heteroptera*, with each zone width of about 1.0–7.5 km. In the northern nature reserve, *P. australis* is concentrated in patches east and northeast of the Qian' er' er management station, while from Gubei Reservoir to the seawall, the sequence is *P. australis*, *T. chinensis*, and *S. heteroptera*, with each zone width of about 10.5–22.0 km.

The regional land cover shows clear ecological succession sequences: (1) a lateral sequence from river channel to both sides developing as river channel → protective forest → *P. australis* → *T. chinensis* → *S. heteroptera*; and (2) a longitudinal sequence along the current river course from sea to land developing as *S. heteroptera* → *T. chinensis* → *P. australis.* These patterns are more pronounced in the eastern protection zone [14].

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## 2. Relationship Between Vegetation Community Distribution Patterns and Key Environmental Factors

**2.1 Ordination and Classification** Analysis of 20 plots using DCA yielded eigenvalues of 0.772, 0.361, 0.191, and 0.084 for the four ordination axes, respectively, with a cumulative contribution rate of 75.1% for the first two axes. This meets the criterion that cumulative contribution rates reaching 75% can reflect the fundamental vegetation characteristics, indicating satisfactory ordination results [Figure 2: see original paper].

Following Song Chuangye et al. [15] and He Qiang et al. [16], we used Two-Way Indicator Species Analysis (TWINSPAN) to classify the 20 plots into four main community types . The DCA ordination revealed distinct ecological meanings for each axis. Community associations showed clear gradient changes along the first axis, corresponding from left to right to *Suaeda heteroptera*, *Tamarix chinensis*, *S. heteroptera*–*T. chinensis* mixed, and *Phragmites australis* vegetation types. The first axis positively represented increases in topographic elevation and groundwater depth, while the second axis primarily reflected surface soil organic matter content.

The gradient length of the first DCA axis was 3.517, indicating significant species distribution responses to environmental gradients and supporting the use of unimodal-based ordination methods. DCCA ordination was subsequently applied using topographic elevation, groundwater depth, chloride concentration and TDS in phreatic water, surface soil chloride content, organic matter content, and pH as environmental variables.

**2.2 Influence of Key Environmental Factors on Plant Distribution Patterns** DCCA eigenvalues for the first four axes were 0.727, 0.242, 0.137, and 0.086, respectively, with species-environment correlations of 0.972, 0.842, 0.544, and 0.742. The first two axes cumulatively explained 72.9% of the total variance in species-environment relationships, indicating good ordination performance [16] .

In ordination diagrams, environmental factors are represented by arrows whose lengths and angles with ordination axes reflect correlation magnitudes—longer arrows indicate larger absolute correlation coefficients [17-19]. The arrow for chloride concentration in phreatic water was longest with a small angle to the first axis, showing the highest correlation (R = -0.938), followed by topographic elevation and groundwater depth (R = -0.800 and -0.623, respectively). Surface soil chloride content also showed strong correlation with the first axis (R = -0.606) .

The first ordination axis primarily reflected the water-salt gradient of chloride concentration in phreatic water and surface soil, while the second axis represented surface soil organic matter content. Community types were arranged along the first axis in the order: *Suaeda heteroptera* → *Tamarix chinensis* → mixed community → *Phragmites australis*, clearly showing community succession along the water-salt gradient. As phreatic water chloride concentration decreased, communities evolved from *S. heteroptera* toward *P. australis*.

Comparing the spatial distribution of these key factors with NDVI revealed high similarity [9]. Single-factor correlation and multiple stepwise regression analyses (after normality testing and outlier removal) showed that NDVI was significantly correlated with six environmental factors, particularly groundwater depth and surface soil chloride content (R = -0.740 and -0.737, respectively) [Figure 4: see original paper].

NDVI showed positive correlations with groundwater depth and topographic elevation (R = 0.468 and 0.330) and negative correlations with surface soil chloride content and phreatic water chloride concentration (R = -0.740 and -0.737). Logistic curve fitting yielded $R^2$ values of 0.65 and 0.60 for relationships with groundwater depth and topographic elevation, respectively, while linear models were suitable for surface soil chloride content ($R^2$ = 0.22 and 0.11).

Multiple stepwise regression analysis introduced surface soil chloride content and groundwater depth into the model, establishing a ternary linear regression equation with significant $R^2$ values. Even when using only surface soil chloride content and groundwater depth, the binary regression equation achieved an $R^2$

only 0.02 lower than the ternary model, highlighting the dominant role of water-salt factors. Further analysis revealed that surface soil chloride content effects on vegetation were actually mediated by groundwater depth and phreatic water chloride concentration, as groundwater (depth 0.5–2.5 m, mostly exceeding critical thresholds) transports water and salts upward through the vadose zone via hydraulic gradients or plant transpiration.

These results demonstrate that groundwater is the dominant environmental factor controlling vegetation growth and distribution in the Yellow River Delta, with groundwater depth and phreatic water chloride concentration being two key factors—particularly the latter, whose gradient changes from river channel to both sides importantly control natural vegetation distribution patterns.

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## 3. Conclusions

(1) DCCA and DCA ordinations showed similar overall patterns, but DCCA more clearly revealed that the first axis represents key water-salt factors, particularly phreatic water chloride concentration. As chloride concentration decreases, communities succeed from *Suaeda heteroptera* to *Phragmites australis*.

(2) Statistical analyses demonstrate that vegetation distribution patterns and NDVI in the Yellow River Delta are primarily controlled by surface soil chloride content and groundwater depth. However, because groundwater is shallow regionally, the effects of surface soil chloride on vegetation are actually mediated by groundwater depth and phreatic water chloride concentration.

(3) Groundwater is the most sensitive ecological factor affecting vegetation growth and distribution in the Yellow River Delta, with groundwater depth and phreatic water chloride concentration being two key factors—especially the latter, whose gradient changes exert important control over natural vegetation distribution patterns.

For coastal wetland protection and ecosystem health maintenance, attention should be paid to increased groundwater chloride concentration caused by dried-up river courses, seawater intrusion, and shoreline erosion. Measures such as full utilization of ecological regulations in the lower Yellow River can help accelerate sustainable development of coastal wetland vegetation.

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*Note: Figure translations are in progress. See original paper for figures.*