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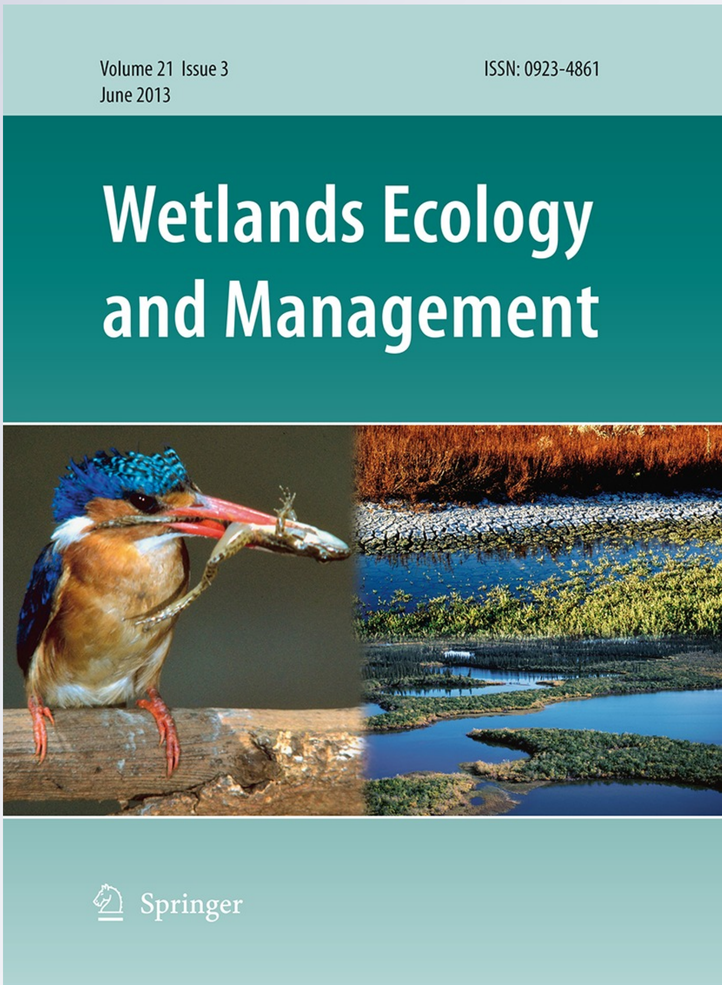

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ORIGINAL PAPER

Succession of aquatic macrophytes in the Modern Yellow River Delta after 150 years of alluviation

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Abstract This study evaluated the succession process of aquatic macrophytes after 150 years of alluviation in the Modern Yellow River Delta, China, and identified the roles of various environmental parameters that regulate vegetation succession. From 2007 to 2008, 214 quadrats were surveyed and 19 environmental parameters were measured, including elevation, plot distance from the seashore, 10 water parameters, and 7 soil parameters. Forty-six aquatic macrophytes belonging to 20 families and 34 genera were identified across the entire delta. Emergent and submerged plants were the most frequent species, accounting for 58.7 and 34.8 % of all species, respectively. Detrended canonical correspondence analysis showed that the presence of aquatic macrophytes in this delta was primarily regulated by water salinity, soil salinity, and distance from the seashore, followed by nutrient concentrations (e.g., NH_4^+, total soil N and PO_4^- of water). Salinity-tolerant species (e.g., *Ruppia maritima*, *Phragmites australis*, and *Typha angustifolia*) tended to be widely distributed across the entire delta. In contrast, salinity-sensitive species (e.g., *Ceratophyllum demersum*, *Hydrilla verticillata*, and *Potamogeton malaianus*) tended to be distributed in areas at the early stages of succession, which were relatively distant from the shore. Moreover, this study also confirmed that species richness and diversity were negatively correlated with water and soil salinity, which in turn were negatively correlated with plot distance from the shore. These data indicate that the primary drivers of aquatic macrophyte succession in this delta are water and soil salinity. The information assimilated here is used to propose management practices for the protection of aquatic macrophytes in the Yellow River Delta.

Keywords Aquatic macrophytes · Environmental factors · Modern Yellow River Delta · Succession · Salinity tolerance

Introduction

Succession may be defined as the non-seasonal and continuous process of colonization and extinction of species populations at a given site (Martínez et al. 2001). Estuarine wetlands serve as a dynamic interface

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between ocean, river, and terrestrial ecosystems that support valuable ecological habitats for organisms, provide ecological services for local residents, and have the highest productivity compared to all other terrestrial and marine systems (Watson and Byrne 2009; Bai et al. 2012). Estuarine wetlands usually contain steep environmental gradients, such as salinity, across landscape scales (Bertness and Ellison 1987; Crain et al. 2008). Wetland plants subject to this strong salinity gradient are hypothesized to reflect this transition, ranging from systems of lower diversity, which are generally dominated by perennial grasses in salt marshes, to systems of higher diversity, containing grasses and forbs in oligohaline marshes (Crain et al. 2008). For this reason, estuaries are considered an ideal system for the study of vegetation succession.

Aquatic macrophytes are of central importance in the structuring of aquatic ecosystems, as these plants food and shelter for other organisms, stabilize sediments, and are important for nutrient cycling (Mckee et al. 2002; Li et al. 2006). In estuarine wetlands, aquatic macrophytes are usually used to monitor environmental changes, due to their environmental sensitivity (Lacoul and Freedman 2006; Ji et al. 2009). Moreover, different macrophytes species usually exhibit different distribution patterns, due to differences in vegetation characteristics and environmental heterogeneity (Lacoul and Freedman 2006; Zhao et al. 2009). Therefore, aquatic macrophytes are one of the most suitable plant groups for studying the succession of wetland vegetation. To date, studies have increasingly focused on the succession of aquatic macrophytes in different wetland ecosystems (e.g., river, lake, stream, and estuarine systems) (Van Geest et al. 2005; Hrivnák et al. 2007; Kwon et al. 2007; Zhang et al. 2007).

Spatio-temporal variation in the composition of wetland plant assemblages is influenced by a large number of factors, including disturbance, water regime, and soil composition (Watt et al. 2007). For estuarine wetlands, salinity is usually considered as the most important factor that regulates the direction and dynamics of vegetation succession (Li et al. 2008; Ji et al. 2009). However, in the Olifants estuary, South Africa, Bornman et al. (2008) found that soil moisture is the primary factor regulating succession. In addition, soil texture, pH, nitrogen, sedimentation, and potassium are also important factors influencing vegetation succession (Rogel et al. 2001). In general, the factors driving succession clearly vary with spatial and temporal heterogeneity, as well as study scales (Mackay et al. 2003).

The Modern Yellow River Delta (YRD) is the largest estuarine wetland in China. In addition, this delta is also one of the most active regions of land–ocean interaction compared to other major river deltas across the world (Zhang et al. 2007; Cui et al. 2009). Large amounts of sediment ($\sim 11 \times 10^8$ t a^{-1}) are carried downstream by the Yellow River, which are then deposited at the river mouth, resulting in the formation of new areas of wetland. The average rate of land formation is about 30 km^2 per year (Cui et al. 2009; Gao et al. 2012). Moreover, due to natural and anthropogenic disturbance, the course of the Yellow River has been altered ten times since 1855 (Fig. 1; Xu 2008). Therefore, this delta may be considered as an integration delta that is composed of 10 sub-deltas with different ages (Fig. 1; Xu 2008). This special pattern of formation has resulted in the delta containing high environmental and vegetation heterogeneity; consequently, this delta represents a highly suitable wetland for studying vegetation succession. To date, many studies have been conducted on vegetation succession in this area; however, these studies have been restricted to the Yellow River Delta Nature Reserve, and were primarily focused on halophytes (Li 1993; Zhang et al. 2007). Consequently, information about the succession of aquatic macrophytes across the entire delta remains limited. This paper aims to assess vegetation succession across the entire delta, with a specific focus on (1) presenting the composition and diversity status of aquatic macrophytes, and (2) clarifying the relationship between vegetation succession and various environmental parameters.

Materials and methods

Study site

The Modern Yellow River Delta (117°31′–119°18′E, 36°35′–38°16′N) is located to the northeast of Dongying City, Shandong Province, China, and covers an area of 5,400 km^2 (Li et al. 2009). The delta faces the Bohai Sea to the north, and borders Laizhou Bay to the east, with an average elevation of less than 15 m above sea level. This delta has some of the highest biodiversity in the world, and supports a wide variety of flora and fauna. It is also an important stopover wintering habitat and breeding

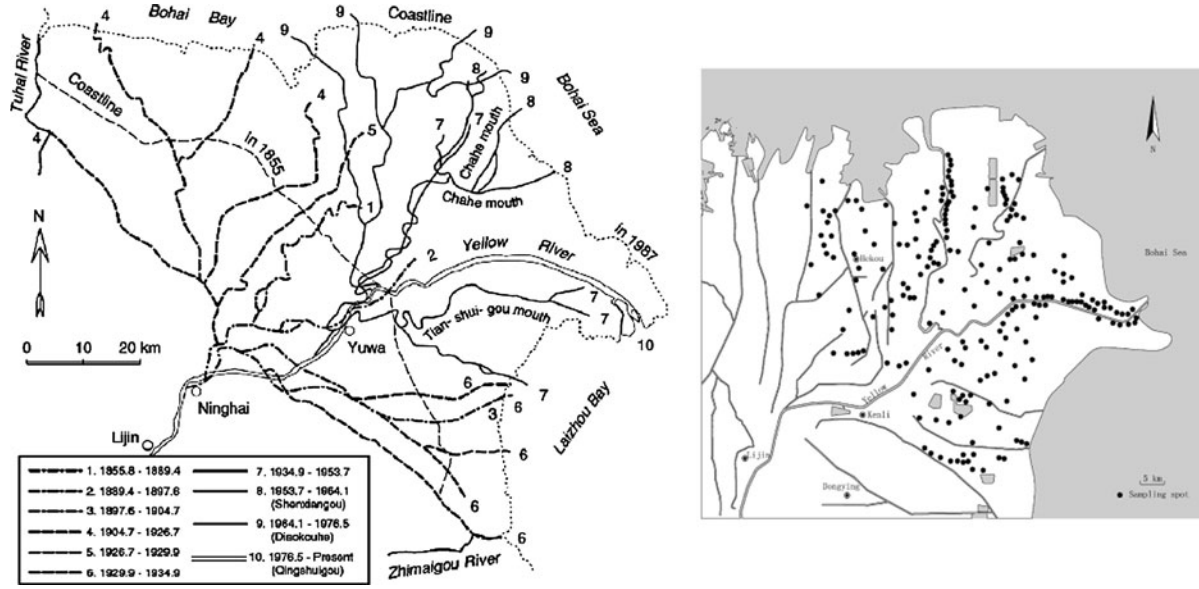

Fig. 1 Location and year of establishment of the field sampling plots along the Modern Yellow River Delta (Xu 2008)

site for birds migrating inland to Northeast Asia and to the Western Pacific Rim (Cui et al. 2009). However, as a recently formed wetland ecosystem, the environment in this delta is highly vulnerable, and has been severely damaged by China's second largest oil field (Shengli Oil Field) and extensively developed agricultural system (Zhang and Sun 2005).

The climate in the YRD is warm temperate with continental monsoons. The annual mean temperature ranges from 11.5 to 12.4 °C, with July and January having the highest and lowest temperatures of 26.6 and −4.1 °C, respectively. The delta is located in a semi-arid zone. Annual rainfall is ~590.9 mm, and the rate of evaporation is over 1,500 mm. The maximum and minimum monthly rainfall is 227 mm in July and 1.7 mm in January, respectively (Cui et al. 2009).

Sampling

The aquatic habitats were investigated during July of 2007 and 2008, when plant growth is optimal, allowing for easy identification. Aquatic habitats were defined as water bodies that contained dominant aquatic vegetation (Wang et al. 2008), including rivers, lakes, marshes, ponds, puddles, channels, estuarine waters, aquafarms, and reservoirs. A total of 214 quadrats (1×1 m^2) were surveyed, comprising 124 quadrats in 2007 and 90 quadrats in 2008 (Fig. 1). The presence, height, number, and coverage of each species were recorded in each quadrat. Species coverage (percentage of each species) was determined by visual estimates. Aquatic macrophytes were identified following the description of Cook (1990), and their life forms were divided into 4 groups: submerged, emergent, floating, and free-floating. During the investigation, the elevation and geographic coordinate of each plot were recorded using a Global Position System (Magellan Company).

Environmental analyses

Seventeen environmental parameters were determined in the second survey: 10 water parameters (NO_3^-, NH_4^+, PO_4^-, total P, total N, transparency, salinity, depth, dissolved oxygen, and pH) and 7 soil parameters (organic matter, total N, total P, NH_4^+–N, NO_3^-, pH, and salinity). The salinity of water and soil were expressed as conductivity, due to their being significantly correlated (Zhang et al. 2003). The conductivity, pH, and dissolved oxygen of water were measured using a portable multi-parameter water quality tester (HANNA HI9820, Italy). Depth was measured to the nearest millimeter. Water transparency was recorded using a Secchi disc (Gu et al. 2005). NO_3^-, NH_4^+, total N, total P, and the PO_4^- of water were measured within 24 h of collection using a portable multifunction water quality analyzer (Lovibond ET99722). Soil samples of 0–20 cm depth were collected from each quadrat, and then immediately transported to the Key Laboratory of Agro-ecological Processes in Subtropical Region, The Chinese Academy of Sciences. The samples were stored in the laboratory at 4 °C until analysis. Soil total N was measured using the semi-micro Kjeldahl method (Bao 1999), while soil total P was measured using NaOH fusion and colorimetric procedures (Olsen and Somers 1982). Soil organic matter was analyzed using the potassium dichromate-volumetric method (Bao 1999). Soil pH was determined in solution with a ratio of 1:2.5 (w/v) dry soil to distilled water using a Mettler Toledo 320 pH meter (Mettler-Toledo Instruments Ltd., China). Soil conductivity was measured in a solution with a ratio of 1:2.5 (w/v) soil to solution using a DDS-11C EC sensor (Shanghai Precision Instrument Co., Ltd. China). The NO_3^- and NH_4^+ of soil were analyzed by flow injection analysis using a Flastar 5000 Analyzer (Foss Tecator Ltd., Sweden) after 2 M KCl extraction (Wang et al. 2005).

Data analysis

Species richness was expressed using the Odum index, and calculated as:

$$D = \frac{S}{LnN},$$

where S is the number of species, and N is the total number of individuals of all species.

Species diversity was expressed by the Shannon–Weiner index, and calculated as:

$$H_i = -\sum_{i=1}^{S} P_i \log_2 P_i,$$

where P_i is estimated as the proportion of total abundance (i.e., relative number) occurring as species i.

On the basis of various iterations, we found that the relationship between vegetation and environmental variables was best resolved using detrended canonical correspondence analysis (DCCA), which has some advantages over other ordinations because it allows easier interpretation of the figure axes (terBraak and Šmilauer 2002). DCCA was conducted using CANOCO vers.4.5. The vegetation data matrix included the importance values of species with a presence frequency of >5 %. The environmental data matrix consisted of 19 environmental parameters; specifically, elevation, distance from the shore, 10 water parameters, and 7 soil parameters. Plot distance from the shore was calculated using Google Earth software based on the geographic coordinate of each plot.

Relationships between the salinity of water and soil, species characteristics (richness and diversity), and plot distance from the shore were analyzed using SPSS 15.0 software. Moreover, curve estimation was performed, from which we selected the “best fit” relationship for each statistical analysis, i.e., the highest R^2 and the lowest P value (Ni et al. 2007).

Results

Composition of aquatic macrophytes across the entire delta

Forty-six species belonging to 20 families and 34 genera were identified across the entire delta. In total, 54.3 % of all aquatic species belonged to the Potamogetonaceae, Poaceae, Cyperaceae, and Hydrocharitaceae families. Poaceae was the most species-rich family, accounting for 17.4 % of the total recorded species. Species-poor families (for which only 1 species was present) included Nymphaeaceae, Juncaceae, Cruciferae, Haloragidaceae, and Ruppiaceae. The most common genera were *Potamogeton* and *Scirpus*, containing 10.9 and 8.7 % of all species, respectively. Emergent, submerged, floating, and free-floating species accounted for 58.7, 34.8, 2.2, and 4.3 % of all species, respectively (Table 1).

DCCA ordination

The first two DCCA axes explained 9.1 and 4.5 % of the species dataset variability, and 30.6 and 15.1 % of the species environmental relationships, respectively. The first DCCA axis was positively correlated with water and soil salinity, total P, and NH_4^+ of soil, dissolved oxygen, total N, and NO_3^- of water (Table 2; Fig. 2). In comparison, this axis was negatively correlated with elevation, distance from the shore, and NO_3^- of soil (Table 2; Fig. 2). The second DCCA axis was positively correlated with soil NH_4^+, soil salinity, PO_4^-, total N, and water salinity, and

Table 1 Species list of aquatic macrophytes in the Yellow River Delta

Groups	Species name
Submerged plants	*Potamogeton malaianus*, *Potamogeton pectinatus*, *Hydrilla verticillata*, *Ceratophyllum demersum*, *Ceratophyllum oryzetorum*, *Vallisneria natans*, *Potamogeton crispus*, *Myriophyllum spicatum*, *Najas major*, *Potamogeton perfoliatus*, *Potamogeton pusillus*, *Ruppia maritima*, *Najas minor*, *Zostera marina*, *Egeria densa*, *Chara* sp.
Floating-leaved plants	*Polygonum amphibium*
Floating plants	*Lemna aequinoctialis*, *Spirodela polyrrhiza*
Emergent plants	*Scirpus validus*, *Acorus calamus*, *Sparganium stoloniferum*, *Echinochloa crusgalli*, *Oryza sativa*, *Typha minima*, *Nasturtium officinale*, *Phragmites australis*, *Miscanthus sacchariflorus*, *Oenanthe javanica*, *Oenanthe henghalensis*, *Ottelia alismoides*, *Juncus effuses*, *Scirpus trangulatus*, *Nelumbo nucifera*, *Polygonum flaccidum*, *Scirpus trigueter*, *Scirpus yagara*, *Typha angustifolia*, *Juncellus serotinus*, *Alisma orientale*, *Calamagrostis pseudophragmites*, *Aeluropus littoral* var. *sinensis Debeau*, *Imperata cylindrica*, *Eleocharis congesta*, *Glyceria acutiflora*, *Carex* sp.

Table 2 Correlation between the environmental parameters and species ordination axes

Environmental factors	Axis-1	Axis-2
Elevation	**−0.3071****	−0.1453
Distance	**−0.4075*****	−0.1847
TP(W)	−0.0644	0.0554
OM	0.0843	−0.1752
TN(S)	0.0987	**−0.2394***
TP(S)	**0.3177****	−0.0521
pH(S)	0.1049	−0.1030
Con(S)	**0.6743*****	**0.3027****
Con(W)	**0.6867*****	**0.3642****
WD	−0.1488	0.0710
pH(W)	0.1875	0.0398
DO	**0.4065*****	−0.1342
Tra	0.1186	0.1608
NN(W)	0.2119*	−0.0992
AN(W)	0.0327	0.0545
TN(W)	**0.2833****	**0.2162***
PO_4^-(W)	0.0037	**0.3214****
NN(S)	**−0.2829****	**−0.2929****
AN(S)	**0.3038****	**0.2488****
Eigenvalues	0.715	0.349
Species–environment correlations	0.861	0.771
Cumulative percentage variance of species data	9.1 %	13.6 %
Of species–environment relation	30.6 %	45.7 %

OM organic matter of soil, *TN(S)* total N of soil, *TP(S)* total P of soil, *NN(S)* NO_3^- of soil, *AN(S)* NH_4^+ of soil, *pH(S)* pH of soil, *Con(S)* conductivity of soil, *Con(W)* conductivity of water, *WD* water depth, *pH(W)* pH of water, *DO* dissolved oxygen of water, *Tra* transparency of water, *NN(W)* NO_3^- of water, *AN(W)* NH_4^+ of water, *TN(W)* total N of water, *TP(W)* total P of water; *PO_4^-(W)* PO_4^- of water

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

negatively correlated with the NO_3^- and total N of soil. The salinity of water and soil were most strongly related to DCCA axis 1, with correlation coefficients of 0.69 and 0.67, respectively (Table 2). Along with DCCA axis 1, there was an apparent shift from *Ceratophyllum demersum* and *Potamogeton malaianus*

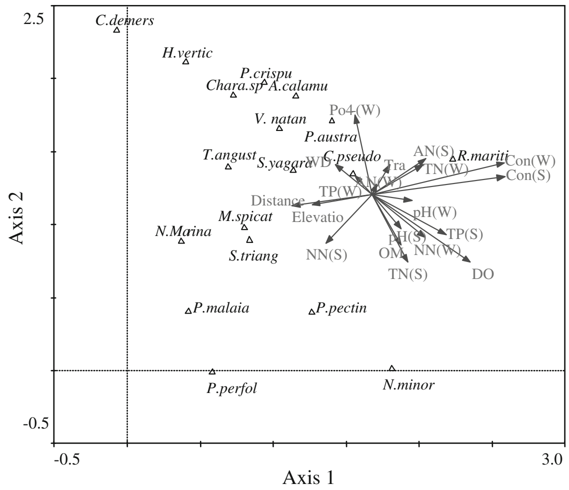

Fig. 2 DCCA ordination for the species and 19 environmental parameters in the Modern Yellow River Delta

to species like *Ruppia maritime* and *Najas minor*. The species at the top of axis 2 included *C. demersum*, *Potamogeton crispus*, *Acorus calamus*, and *Hydrilla verticillata*. Species such as *N. minor* and *Potamogeton pectinatus* were located on the lower part of axis 2 (Fig. 2).

Dominant aquatic macrophyte distributions based on salinity and distance ranges

There was major variation in the salinity ranges of different species. The widest salinity ranges were recorded for *R. maritima*, *Phragmites australis*, and *Typha angustifolia*. In contrast, *C. demersum*, *H. verticallata*, and *P. malaianus* were primarily distributed in low salinity conditions (Table 3). Moreover, the distance ranges from the shore also changed significantly among species. The species with the greatest distance ranges also had the widest salinity ranges. In contrast, saline-sensitive species, such as *H. verticallata*, *Acorus calamus*, and *Vallisneria natans*, were usually distributed away from the shore (Table 3).

Relationship among species characteristics, plot distance from the shore, and the salinity of water and soil

Species richness declined significantly with increasing water (F = 59.919; $P < 0.001$; Fig. 3) and soil salinity (F = 42.108; $P < 0.001$; Fig. 3). Moreover, species diversity displayed similar patterns to that of species richness, which rapidly decreased with

Table 3 Salinity and distance ranges from the shore for the distribution of dominant aquatic macrophytes in the Modern Yellow River Delta (based on the results of the field investigation)

Species	Water salinity (ms cm^{-1})	Soil salinity (ms cm^{-1})	Distance from shore (km)
Phragmites australis	0.51–33.42	0.15–10.96	4.23–82.32
Typha angustifolia	0.91–23.78	0.31–5.57	4.23–78.54
Calamagrostis adans	0.91–10.45	0.27–5.57	17.02–30.26
Scirpus triangulatus	0.51–16.09	0.34–3.97	5.41–65.34
Scirpus yagara	1.47–14.03	0.24–3.97	4.23–18.24
Myriophyllum spicatum	0.51–16.46	0.15–4.37	12.81–81.38
Najas marina	1.19–14.03	0.24–3.97	12.81–68.39
Potamogeton malaianus	1.19–4.29	0.39–1.31	16.78–65.34
Potamogeton pectinatus	1.19–11.94	0.31–5.57	16.13–82.32
Potamogeton crispus	1.19–6.71	0.32–3.97	12.81–68.39
Najas minor	2.02–16.09	1.10–9.08	33.86–71.87
Chara sp.	1.19–13.18	0.39–5.97	17.02–68.39
Vallisneria natans	1.19–9.25	0.39–9.08	34.07–65.34
Potamogeton perfoliatus	1.98–9.26	0.32–2.19	16.78–82.32
Hydrilla verticallata	1.19–3.13	0.32–5.57	34.07–80.50
Ceratophyllum demersum	1.50–7.74	0.34–2.34	16.88–59.30
Ruppia maritima	1.30–43.94	1.21–12.38	4.70–82.32
Acorus calamus	1.19–6.70	0.32–1.29	29.86–67.66

increasing water (F = 20.792; $P < 0.001$; Fig. 3) and soil salinity (F = 10.493; $P < 0.05$; Fig. 3).

A significantly negative correlation was found for plot distance from the shore with respect to water (F = 21.761; $P < 0.05$; Fig. 4) and soil salinity (F = 10.993; $P < 0.05$; Fig. 4). With increasing distance from the shore, the salinity of water and soil decreased significantly (Fig. 4).

Discussion

In this study, 46 species belonging to 20 families and 34 genera were identified in the YRD, accounting for 11.22, 30.91, and 39.22 % of total species, families, and genera of aquatic plants in China, respectively (Yan 1983). Compared to other wetlands, the diversity of aquatic macrophytes is relatively low in this delta.

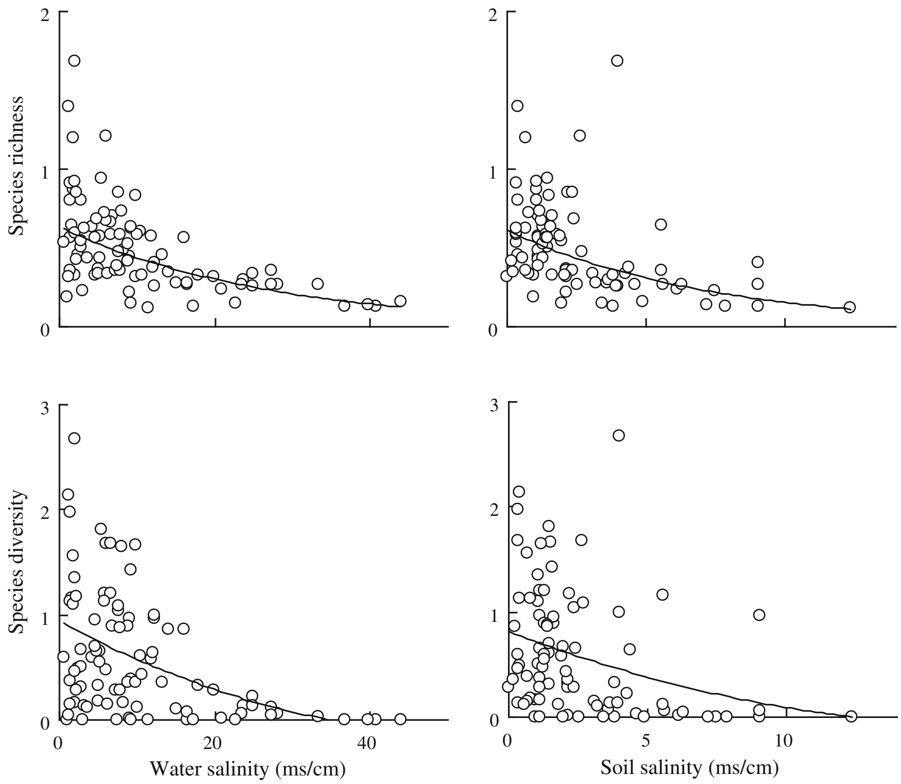

Fig. 3 Relationship between the vegetation characteristics and the salinity of water and soil in the Modern Yellow River Delta

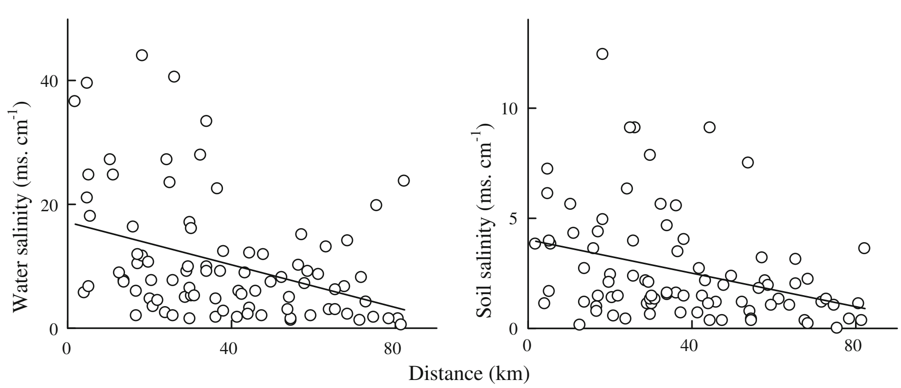

Fig. 4 Relationship between plot distance from shore and the salinity of water and soil in the Modern Yellow River Delta

Bertoli (1996) identified a total of 100 species in the Orinoco River Delta of Venezuela. The lower diversity of aquatic macrophytes in the YRD might be attributed to its young age (ca. 150 years) and disturbed environments. The YRD is subject to frequent disturbance from the dynamic interactions of the ocean, land, and river. The wetlands are degraded by frequent disasters, including coastal erosion, tidal, wave current, storm surge flood, and sea level rise. In addition, these disasters impact aquatic macrophytes by uprooting seedlings, damaging mature plants, and eroding the sediment (Lacoul and Freedman 2006). Furthermore, oil exploration and agricultural development, as well as other human activities, have intensified since the 1960s, leading to serious environmental deterioration in this delta (Zhang and Sun 2005). Consequently, the habitats have been seriously damaged, which has significantly limited the colonization, survival, and propagation of aquatic macrophytes.

The DCCA ordination results showed that the presence of aquatic macrophytes in the YRD was primarily determined by the salinity of water and soil, followed by various nutrient concentrations, such as the total P and total N of soil and NO_3^- levels in soil and water. Previous studies have also confirmed the role of salinity in regulating the vegetation succession of other estuarine wetlands (Li et al. 2008; Ji et al. 2009). In addition, the current study also confirmed that species richness and diversity clearly decreases with increasing water and soil salinity. In this delta, the water and soil salinity was not spatially uniform. Hence, aquatic macrophyte distribution occurs as a consequence of the differential abilities of these plants to colonize and become established in areas with locally restricted salinity conditions. In general, salinity is higher in newly forming areas (e.g., areas formed during 1964–1976 and 1976-present; Fig. 1) compared to older areas (e.g., areas formed during 1855–1889 and 1889–1897; Fig. 1), due to a higher intensity of seawater erosion. Therefore, aquatic macrophytes in these newly forming areas are usually saline-tolerant species, such as *R. maritima* and *P. australis*, which are able to survive in waters of 43.9 and 33.4 ms cm^{-1} electrical conductivity, respectively. However, some highly saline-sensitive species (e.g., *H. verticillata*, *C. demersum*, and *P. pectinatus*) cannot survive such conditions (Lacoul and Freedman 2006). The environment was ameliorated by these early colonists, in conjunction with ongoing succession. When the salinity decreased to a certain level, some saline-sensitive species began to colonize older areas. This result is consistent with our study findings, which showed that such saline-sensitive species are usually distributed far from the shore. In addition to salinity, axis 1 was also significantly correlated to other environmental factors; specifically, elevation, plot distance from the shore, and dissolved oxygen. Moreover, we also found that certain factors also interact with each other. For instance, a negative relationship was found between plot distance from the shore and salinity in our study. This result indicates that the process of vegetation succession in the YRD is more complicated compared to other deltas with less sediments and main channel mobility.

In addition to salinity, nutrients also play an important role in controlling the succession of aquatic macrophytes in the YRD, which is consistent with a previous study conducted in the Yellow River Delta Nature Reserve (Song et al. 2008). Aquatic macrophytes, particularly submerged macrophytes, are able to obtain dissolved nutrients from either the sediment or water column (Xie et al. 2005). Nutrient factors have an important influence on the distribution of aquatic macrophytes, and therefore some species may be used as indicators of the trophic status of the habitats in which they grow. For example, *C. demersum* cannot survive in high nitrogen environments (Lacoul and Freedman 2006). The DCCA analysis of the current study placed this species at the top of axis 2, indicating that its distribution is negatively correlated with soil NO_3^- and total N content. However, most aquatic macrophytes were positioned in the middle of axis 2, indicating broad autecological amplitude with respect to various nutrient factors, mainly due to their inherent phenotypic plasticity and physico-chemical variations associated with sediment and water, as well as seasonal inundation (Barko and James 1998).

Soil salinization and water pollution have intensified in the YRD in recent years, which has significantly driven the rate of succession for aquatic macrophytes, as shown by this study. In this delta, reduced freshwater input was the dominant factor causing soil salinization. Runoff is the main source of freshwater to the Yellow River, but levels have significantly declined since the 1950s, with no freshwater reaching the delta wetland on several occasions (Zhang and Sun 2005). In addition, increasing water consumption in agriculture, industry, and human consumption further limits the supply of freshwater to the wetlands. Moreover, with the high-speed development of industries accessing oil and gas resources, along with connected industries and agriculture, more than 40×10^6 m^3 of urban and industrial wastewater is discharged into the sea through local rivers annually, most of which has been inadequately treated (Zhang and Sun 2005).

In conclusion, to conserve and maintain the positive succession of aquatic macrophytes in the YRD, management programs should urgently implement practices that focus on lowering the salinity and nutrient contents of soil and water. To prevent soil salinization, a sufficient freshwater supply to the wetlands should be safeguarded, which might be achieved by optimizing river flow through human projects, enhancing water utilization efficiency, implementing water conservation measures, building reservoirs, and developing new technologies for utilizing silt-laden water from the Yellow River. To prevent pollution, the wastewater generated by local industries and townships should be monitored and treated before drainage, with the introduction of laws being required to prevent the indiscriminate discharge of sewage. More sewage treatment facilities should be constructed, which would reduce water pollution, and contribute toward enhancing the water utilization efficiency of the Yellow River Delta region.

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