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Plant community succession in modern Yellow River Delta, China*

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Abstract: Data were collected in different successional stages using a simultaneous sampling method and analyzed through quantitative classification method. Three large groups and 12 classes were made to represent the community patterns of three succession stages and 12 succession communities. The succession series of plant community in the study area was as follows: saline bare land→community *Suaeda salsa*→community *Tamarix chinensis*→grassland. Succession degree and succession process of 12 succession communities were calculated. Most of these communities were in the lower succession stage, however, community *Phragmites communis*+*Glycine soja* and community *Imperata cylindrica*+*G. soja* were close to the succession stage of grassland climax. Five species diversity indices were used to study the changes in species richness, species evenness and diversity during succession of community. Heterogeneity index and richness index increased gradually during the community succession process, but species evenness tended to decrease with succession development. The relation between succession and environment was studied by ordination technique, and the results showed that the soil salt content was an important factor to halarch succession of the modern Yellow River Delta. It affected community structure, species composition and succession process.

Key words: Community succession, DCA and TWINSPAN analysis, Yellow River Delta
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INTRODUCTION

Plant community succession is an important aspect of vegetation ecology (Leendertse, 1997; Martínez *et al*., 2001; Zhang, 2000). Early studies of succession were restricted to qualitative descriptions of community patterns until Daubenmire (1952) drew attention to the processes potentially driving secondary succession. Later work emphasized rates of change, material cycles and energy flows during succession as well as potential mechanisms regulating species change and population dynamics (Margalef, 1968). Disturbance has also been recognized as important in driving successional processes (Ren *et al*., 2001). The trend in recent years is to study community succession using quantitative methods (Luo, 1994; Li *et al*., 2001; Wang and Jiang, 2002; Baoyin *et al*., 2003; Zhang, 2000; 2005).

The modern Yellow River Delta is located at the mouth of the Yellow River flowing to the sea, north of Shandong Province, China. Due to little disturbance by human, the community succession in this area belongs to primary succession, which is ideal for studying plant succession. This study has important significance for theoretical study on plant succession, and also for studying the dynamical characteristics of plant community, ecological restoration and reconstruction in the area.

MATERIALS AND METHODS

Data collection

For purposes of this study, the Delta was divided into 27 separate areas. Each area was then sampled with either four or five quadrats whose location was selected at random. A total of 124 quadrats were investigated between June and July 2004 (Fig.1).

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Quadrat sizes were 2 m×2 m for shrub-dominated and 1 m×1 m for herb-dominated communities, respectively. The following measurements were recorded for each quadrat:

(1) Longitude and latitude [using a Global Position Systems (GPS)];

(2) Plant species, abundance (Drude's), cover (%), height of the tallest plants, phenophase, accompanying species of outside sample plot;

(3) Total aboveground biomass (dry weight);

(4) Soil samples were collected to a depth of 30 cm deep using a soil drill. Samples from all quadrats within a given area were amalgamated for processing.

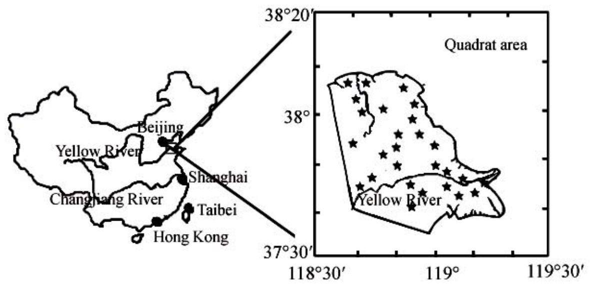

Fig.1 The location of the modern Yellow River Delta and quadrat areas

Data processing

Calculations were as follows:

$$RC_i\ (\%)=C_i/\sum C_i\times 100,$$
$$RD_i\ (\%)=D_i/\sum D_i\times 100,$$
$$RF_i\ (\%)=F_i/\sum F_i\times 100,$$
$$IV=(\sum RF_i+\sum RC_i)/200,$$

where RC_i is relative coverage of species 'i', C_i is the species (i) coverage, $\sum C_i$ is sum of all species coverages; RD_i is relative density of species 'i', D_i is the species (i) density, $\sum D_i$ is sum of all species densities; RF_i is relative frequency of species 'i', F_i is the species (i) frequency, $\sum F_i$ is sum of all species frequencies; IV is the importance value of shrub and herb, $\sum RF_i$ is relative frequency, $\sum RC_i$ is relative coverage.

Shannon-Wiener heterogeneity index (H'):

$$H'=-\sum P_i \ln P_i,$$

Simpson heterogeneity index (DS):

$$DS=1-\sum (N_i/N)^2,$$

Pielou evenness index (JP):

$$JP=-\sum P_i \ln P_i/\ln S,$$

Alatalo evenness index (EA):

$$EA=[1/(P_i)^2-1]/[\exp(-\sum P_i \ln P_i)-1],$$

Margalef richness index (Ma):

$$Ma=(S-1)/\ln N.$$

Here, N_i is the IV of the ith species in a quadrat, N is the sum of IV of all species in the same quadrat, P_i is the proportional IV in a quadrat ($P_i=N_i/N$) and S is the species number in a quadrat (Greig-Smith, 1983).

RESULTS

Classification of successional stages

Two-way indicator species analysis (TWINSPAN) was used to classify community patterns of study area. Using TWINSPAN analysis, a total of 124 samples were classified into three large groups that were further classified into 12 groups, which represented 12 community patterns, based on quadrats investigation data. The 12 groups represented the following communities: I. community dominated by the species *Suaeda salsa* (included I_1, I_2), II. community dominated by *Tamarix chinensis* (II_1, II_2, II_3, II_4), and III. herbaceous community consisting of dominant species *Phragmites communis*, *Echinochloa littoralis*, *Imperata cylindrical* (III_1, III_2, III_3, III_4, III_5, III_6). These three large community patterns consisted of three succession stages. It reflects relations between species and quadrats, and environmental gradient. Each succession stage could be divided into different community stages, which were closely related to the length of time for succession, soil desalinization and soil water status and change of dominant species. The species composition and structural characteristics of each succession stage are as follows.

1. Stage of the community *Suaeda salsa* (I)

S. salsa was the dominant species in the stage and distributed in low-lying land with higher soil salt content near the coastline. It was pioneer community of the modern Yellow River Delta and was initial stage. The pioneer community was an open community stage, along with increasing coverage of *S. salsa*. The soil physical and chemical property and soil structure were ameliorated, and some salt-enduring species began to invade the community and were divided to form the community with dominant species *S. salsa*.

According to community character, this stage could be classified into the following community types:

(1) Community *S. salsa* (I_1)

S. salsa formed a monodominant community. Abundance of the community varied from Sp. to Cop^3. and its coverage was between 5% and 95%. Biomass of the community was 1.22 kg/m^2. The community distributed in low-lying land at an elevation of 1.8 m. Some of them appeared in clustered distribution and others appeared in spotted form (clumps of them separated by salt bare areas).

(2) Community *S. salsa*+*P. communis* (I_2)

S. salsa and *P. communis* dominated in the community and other species were few. Most of them were distributed in low-lying land and region with high soil salt content. Abundance of *S. salsa* varied from Sp. to Soc., and its coverage was between 15% and 95%. *P. communis* had abundant of Sol.~Cop^1. and its coverage was between 2% and 50%. Biomass of the community was 1.02 kg/m^2.

Exceptionally, *Limonium sinesis*, *Scorzonera mongolica*, *Plantago depressa* occurred in few quadrats as accompanying species.

2. Stage of the community *Tamarix chinensis* (II)

After community *S. salsa* developed to certain stage, along with land rising and ground water level falling, community *T. chinensis* was formed as species source of *T. chinensis*. Soil was desalted further in this stage, soil organic matter was richer than that in stage of the community *S. salsa*. Community types in the stage are as follows:

(1) Community *T. chinensis* (II_1)

T. chinensis was the dominant species, which formed monodominant community. The coverage of *T. chinensis* was between 30% and 50%. Its average height was 130~175 cm. The soil where *T. chinensis* distributed had relatively a higher soil salt content.

(2) Community *T. chinensis*+*S. salsa* (II_2)

Dominant species for the community were *T. chinensis* and *S. salsa*, other accompanying species that grew here few, with no other species being found. The coverage for *T. chinensis* was 18%~50%, and was 15%~100% for *S. salsa*. The soil salt content in the community was relatively high.

(3) Community *T. chinensis*+*S. salsa*+*P. communis* (II_3)

The dominant species were *T. chinensis*, *S. salsa* and *P. communis*, with *Artemisia capillaris*, *Imperata cylindrica* and *Metaplexis japonica* accompanying them in a few quadrats. Frequencies for *T. chinensis*, *S. salsa*, *P. communis* and *A. capillaris* were 94%, 94%, 100% and 24% respectively. *I. cylindrica* and *M. japonica* had a frequency of 6%. Coverages of *T. chinensis*, *S. salsa* and *P. communis* were 11%~67%, 2%~90% and 2%~70% respectively. Abundances of *S. salsa* and *P. communis* were Sol.~Soc., Sol.~Cop^2. respectively. Except *T. chinensis*, biomass of the community was 0.054 kg/m^2.

(4) Community *T. chinensis*+*S. salsa*+*Limonium sinesis* (II_4)

T. chinensis was dominant species, *S. salsa* and *L. sinesis* were subdominant species. *Phragmites communis* and *Aeluropus littoralis* occurred in some quadrats as accompanying species. The frequencies of the former three species all were 100%, and were 80% and 40% for *P. communis* and *A. littoralis* respectively. Coverage of *T. chinensis* was 7%~30%, and was 2%~40% and 5%~40% for *S. salsa* and *L. sinesis* respectively. Abundance of *S. salsa* was between that of Sol. and Cop^2., and *L. sinesis* had abundance of Sol.~Cop^1. Biomass in the community was 0.04 kg/m^2.

3. Grassland stage (III)

Grassland stage developed from two succession paths. One of the paths was from the community *S. salsa*. Along with growth of species *S. salsa*, soil was desalted, but groundwater level changed little, its habitat was water logging the whole year or rain season. As *S. salsa* could not endure perennial water logging, it was replaced by the community *P. communis*. *P. communis*'s growth produced a lot of litter fall, which speeded up process of land rising and soil desalinization, soil was gradually improved, and soil salt content decreased further. Some salt-enduring and hygrophilous species began to invade the community, *P. communis* was gradually replaced by species *A. littoralis* and *L. sinesis*, and evolved to the community *I. cylindrica*. They formed different grassland. Another path was from the community *T. chinensis*. *T. chinensis*'s growth increased in coverage, and speeded up the process of soil desalinization. Along with soil salt content decreasing, some salt-enduring species began to invade and developed to community of *T. chinensis*+*A. littoralis*, *I. cylindrica*. The community types in this stage were as follows:

(1) Community *P. communis*+*S. salsa*+*Apocynum venetum*+*M. japonica* (III_1)

P. communis was absolutely dominant in the community, although *S. salsa*, *A. venetum* and *M. japonica* were also present. Frequencies of *S. salsa* and *P. communis* all were 100%, other species, *A. venetum* and *M. japonica*, had frequencies of 50% and 66% respectively. This class was divided into two types of communities, which were the community of *P. communis*+*S. salsa*+*A. venetum* on condition that *A. venetum* appeared and the community of *P. communis*+*S. salsa*+*M. japonica* if *M. japonica* distributed. The abundance of *P. communis* varied from Sol. to Soc. and its coverage was from 10% to 90%. The abundance and coverage of *S. salsa* were less than that of *P. communis*, its values were Sol.~Cop^1. and 1%~50%. Other species, *A. venetum* and *M. japonica*, had the least value. Biomass of the community was 0.2 kg/m^2.

(2) Community *P. communis*+*M. japonica*+*A. capillaries* (III_2)

The dominant species in the community was *P. communis*, *M. japonica* and *A. capillaris* were subdominant species. In some quadrats, the species *Glycine soja*, *Echinochloa littoralis*, *Cirsium segetum*, *Polygonum orientale* and *M. japonica* were subdominant species. Frequencies of *P. communis*, *A. capillaris*, *M. japonica* and *G. soja* all were 100%, but the frequencies of *E. littoralis*, *C. segetum* and *P. orientale* were 75%, 50% and 25%, respectively. The abundances of *P. communis*, *A. capillaris* and *M. japonica* were Cop^2.~Soc., Sol.~Sp. and Sol.~Sp. respectively, and their coverages were 50%~100%, 2%~5% and 2%~5% in that order. Species in the community were rich, there were 11 species that appeared in four quadrats that belonged to the community, and seven species were appeared in one quadrat on an average. Biomass of the community was 2.58 kg/m^2.

(3) Community *E. littoralis*+*Ixeris chinensis*+*P. communis* (III_3)

The dominant species in the community was *E. littoralis*, *I. chinensis* and *P. communis* were subdominant species. Other species, *Potentilia chinensis*, *G. soja*, *Chenopodium glaucum* and *Chenopodium album*, were found as accompanying species in some quadrats. Frequencies of species, *E. littoralis*, *I. chinensis* and *P. communis*, were all 100%, species *G. soja* and *P. chinensis* had frequency of 50%, and *C. glaucum* and *C. album* both were 25%. Abundance of *E. littoralis* was Cop^3.~Soc., and its coverage was 50%~95%. Abundance and coverage of *I. chinensis* were Sol.~Sp. and 2%~10% respectively, and were Sol.~Sp. and 5%~25% for *P. communis*. Species composition in the community was rich, there are ten species in four quadrats and five species appeared in one quadrat on an average.

(4) Community *P. communis*+*G. soja* (III_4)

The dominant species in the community were *P. communis* and *G. soja*. *A. venetum* and *I. cylindrica* were accompanying species in some quadrats, which formed of the community of *P. communis*+*A. venetum* and *P. communis*+*I. cylindrica*. Frequency of *P. communis* was 100%, *G. soja* was 38%, and frequencies of both *A. venetum* and *I. cylindrica* were 25%. Abundance and coverage of *P. communis* were Sol.~Soc. and 5%~90% respectively, and were Sol.~Cop^3. and 5%~40% for *G. soja*. Biomass of the community was 1.85 kg/m^2.

(5) Community *I. cylindrica*+*G. soja* (III_5)

The dominant species in the community were *I. cylindrica* and *G. soja*. As accompanying species, *Conyza canadensis* and *P. communis* were found in some quadrats, and *P. orientale* and *A. capillaris* appeared in a few quadrats. Frequencies of *I. cylindrica*, *G. soja*, *P. communis* and *C. canadensis* were 100%, 89%, 78% and 44%, respectively. Species of the community were rich in composition; there were eleven species in nine survey quadrats (1 m^2 size for each quadrat) and four species appeared averagely in one quadrat. Abundance and coverage of *I. cylindrica* were Sol.~Soc. and 5%~90%, respectively, and were Un.~Soc. and 5%~93% for *G. soja*. Biomass of the community was 1.14 kg/m^2.

(6) Community *Aeluropus littoralis*+*P. communis*+*S. salsa* (III_6)

A. littoralis dominated in the community, and *P. communis* and *S. salsa* were subdominant species. In some quadrats, *L. sinesis* and some wormwood occurred as accompanying species. Frequencies of *A. littoralis*, *P. communis* and *S. salsa* were 100%, 71% and 71%, respectively. For *L. sinesis* and *A. capillaris*, their frequencies all were 14%. Abundances of *A.*

littoralis, *P. communis* and *S. salsa* were Sp.~Soc., Sol.~Cop[1]., Sol.~Cop[1]. respectively, and coverages for these species were 15%~90%, 5%~60% and 5%~30% respectively. Biomass of this community was 0.64 kg/m^2. There were few species that organized the community, three species occurred in one quadrat on an average.

The above-mentioned community succession is the successional series of other area except area of Yellow River mouth. However, succession of the area of Yellow River mouth is hygrocolous successional series. This succession takes Yellow River as axle, and expands to both sides along the riverbank. Plant community types are community *P. communis*+*Miscanthus sacchariflorus*, and community *A. littoralis*+*I. cylindrica* in that order.

Natural succession pattern of plant community in the modern Yellow River Delta is shown in Fig.2. The changes of plant community characteristics in different succession stages are shown in Table 1.

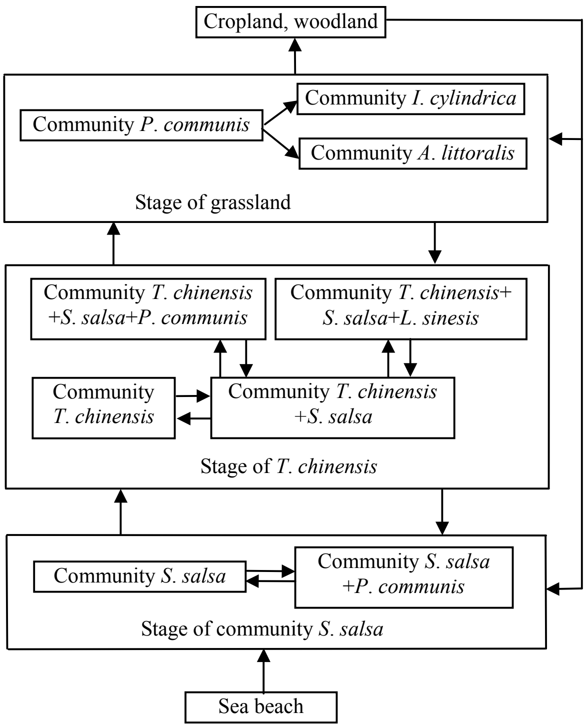

Fig.2 Natural succession pattern of plant community in the modern Yellow River Delta

Analysis of community succession degree and succession process

Using importance values, longevity and coverage of species, the succession degrees of three succession stages and 12 communities in the modern Yellow River Delta were calculated, the results are listed in Table 1 and shown in Fig.3. The succession degrees of communities I_1, II_1, II_4 and III_3 were between 30 and 97.1, the succession degrees of communities I_2, II_3, III_1, III_2 and III_5 were between 103.3 and 184.3, the succession degrees for communities II_2, III_4 and III_6 were between 220.8 and 286.9. According to the succession degree, the communities I_1, II_1 was monodominant community of *S. salsa* and *T. chinensis* respectively, they went through the community *S. salsa*+*P. communis* (I_2) and community *T. chinensis*+*S. salsa*+*L. sinesis* (II_4), and evolved to community *T. chinensis*+*S. salsa*+*P. communis* (II_3), community *P. communis*+*S. salsa*+*A. venetum* (III_1), community *P. communis*+*M. japonica*+*A. capillaris* (III_2) and community *I. cylindrica*+*G. soja* (III_5). Community *P. communis*+*G. soja* (III_4) and community *A. littoralis*+*P. communis*+*S. salsa* (III_6) were higher stage of halarch succession in the modern Yellow River Delta. Succession degrees of communities III_4, III_6 were 286.9 and 230.7 respectively, it was near succession degree (300~400) of grassland climax (Zhang, 1995).

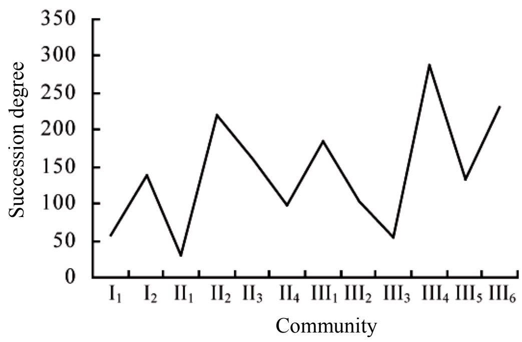

Fig.3 Succession degree of communities

Species diversity change of community succession

Fig.4 shows changes of community diversity, species richness and evenness of different succession stages in the modern Yellow River Delta.

Fig.4 shows that heterogeneity index and richness index increased gradually during the community succession process. In the initial stage of succession, because of a higher soil salt content, only some salt-enduring species of *S. salsa* and *T. chinensis* could grow, so it formed monodominant community of *S. salsa* and *T. chinensis*, or the community

Table 1 The changes of plant community characteristics in different succession stages

Communities	Number of succession species	Diversity		Evenness		Richness	Soil salt content (%)	Succession values
		H'	DS	JP	EA	Ma		
I_1	1	0	0	0	0	0	0.604	57.9
I_2	2	0.71	0.48	0.94	0.93	0.25	0.495	137.3
II_1	1	0	0	0	0	0	0.470	30.0
II_2	2	0.68	0.48	0.98	0.97	0.22	0.503	220.8
II_3	3	0.98	0.56	0.87	0.82	0.48	0.347	160.8
II_4	4	1.36	0.72	0.92	0.88	0.74	0.300	97.1
III_1	4	1.00	0.54	0.79	0.74	0.58	0.267	184.3
III_2	7	1.56	0.69	0.82	0.59	1.25	0.075	103.3
III_3	5	1.35	0.64	0.83	0.66	0.92	0.085	55.4
III_4	4	0.53	0.35	0.69	0.71	0.22	0.235	286.9
III_5	4	1.29	0.66	0.89	0.85	0.75	0.062	134.1
III_6	5	0.94	0.55	0.90	0.86	0.43	0.270	230.7

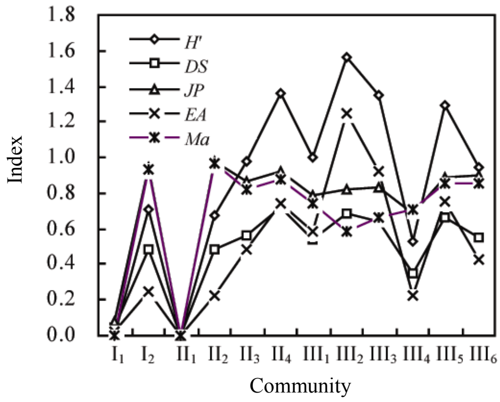

Fig.4 Changes of community diversity, species richness and evenness of different succession stages

consisted of one or two species, species composition was few. Plant habitat was gradually improved with the progressing of succession. Land was rising, soil was desalted further, community of grassland was gradually developed. The number of species formed community increased in this stage. There were often three or four species in one community. The largest number of species for one community was seven. However, when the community developed to a higher succession stage, the number of species forming the community decreased, there were often 3~4 species in one community. It is because roles of constructive and dominant species became more significant in this stage. Coverage of dominant species increased, it restricted other species growth in competition.

Species evenness showed a different pattern of change compared to species heterogeneity index. It fluctuated greatly in initial stage of succession. However its fluctuation became little and tended to decrease with succession development.

Ordination analysis of succession relation

Fig.5 shows a DCA (detrended correspondence analysis) ordination diagram of the 124 quadrats.

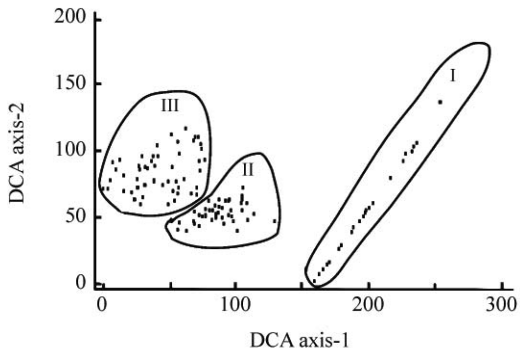

Fig.5 DCA ordination diagram of 124 quadrats in the modern Yellow River Delta

Because eigenvalue of axis-1 is the largest and axis-2 is the second, which contain more ecological information, the first and the second DCA axis are used to draw a two-dimensional scatter diagram. The results reflect quite good relation between community and environment and among community.

DCA axis-1 reflects a succession gradient of time. That is, it represents development process of community succession from an initial stage to a higher stage from right to left along the first axis.

Quadrats (I) on the right show succession stage of *S. salsa* and *T. chinensis*. Soil of these quadrats has higher salt content, species composition is monotypic. The community only consistes of *S. salsa* or *T. chinensis* and forms monodominant community. It is shown that condition of plant habitat is poor, only salt-enduring species *S. salsa* and *T. chinensis* can grow in the habitat.

The quadrats (II) in the middle of ordination diagram represent higher stage than that on the right in the succession process. Community structure is complex, there are often two or three species forming one community. Perennial grasses of *P. communis* and *L. sinesis* have entered the community and become accompanying species. Habitat condition has been improved further. Community structure tends to stabilize.

The quadrats (III) on the left of ordination diagram belong to a quite higher stage. They have developed from the succession stage of *S. salsa* and *T. chinensis* to the stage of grassland. The number of species composing the community increases. One community is often composed of three or four species, at most seven species for one community. The community structure is more complex and the community is more stabilize (Table 2).

Fig.5 reflects also the gradient relation between community succession and environment. Soil salt content of quadrats increases gradually from left to right along the first axis. Soil salt content of the quadrats on the left is 0.17 on an average. The soil salt content of the quadrats in the middle is 0.38. Average soil salt content on the right is 0.54. This shows that the soil salt content is an important factor to halarch succession of the modern Yellow River Delta. It affects community structure, species composition and succession process.

Figs.6~8 show the changes of species heterogeneity (H', DS), evenness (JP, EA) and richness (Ma) with the environment changes.

Table 2 The changes in species number and life-form during the succession stages

Species life-form	Species number in different succession stages											
	I_1	I_2	II_1	II_2	II_3	II_4	III_1	III_2	III_3	III_4	III_5	III_6
Total number of species	1	2	1	2	3	4	4	7	5	4	4	5
Therophytes	1	1	0	1	1	1	1	3	3	1	1	1
Perennial herbs	0	1	0	0	1	2	3	4	2	3	3	4
Shrubs	0	0	1	1	1	1	0	0	0	0	0	0

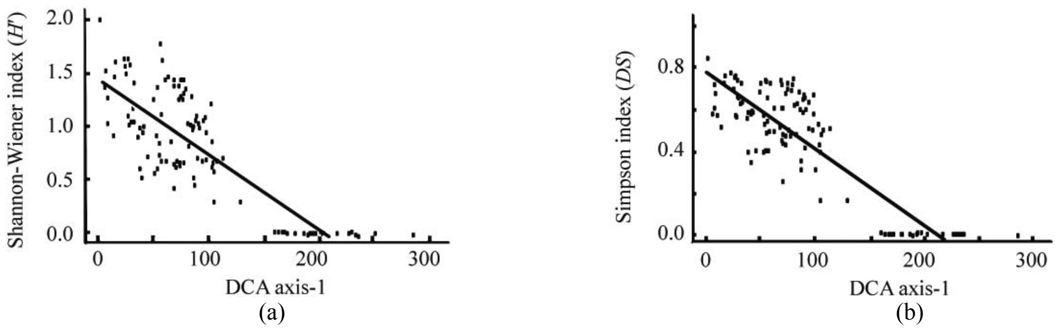

Fig.6 The changes of species heterogeneity. (a) Shannon-Wiener index (H'); (b) Simpson index (DS)

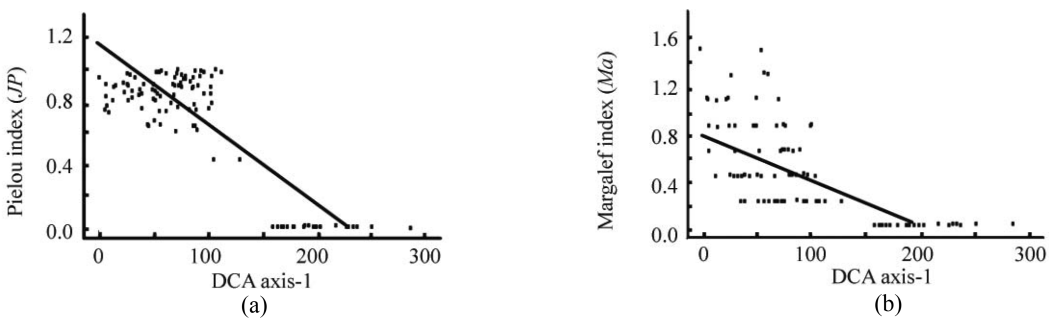

Fig.7 The changes of (a) evenness (JP) and (b) richness (Ma)

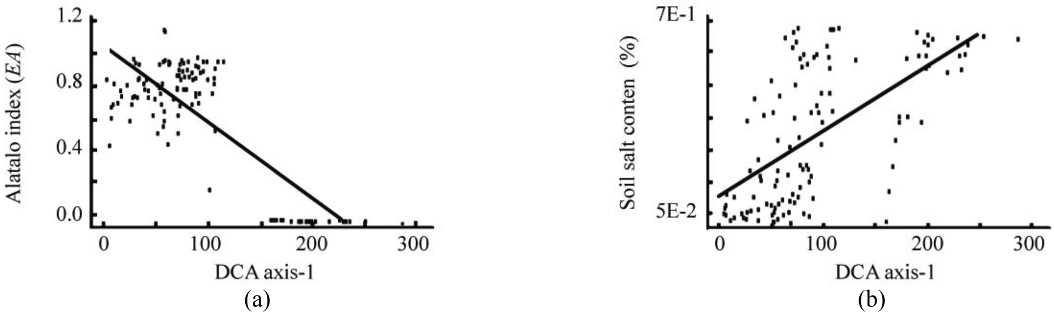

Fig.8 The changes of (a) evenness (*EA*) and (b) soil salt content

Figs.6~8 show that Shannon-Wiener heterogeneity index (H'), Simpson heterogeneity index (DS), Pielou evenness index (JP), Alatalo evenness index (EA), Margalef richness index (Ma) are negatively related to the first DCA axis. That is, species heterogeneity index, evenness index and richness index decrease gradually with increasing of soil salt content of quadrats.

Correlation coefficients for indexes of H', DS, JP, Ma and EA are −0.826, −0.867, −0.855, −0.694 and −0.793 respectively.

DISCUSSION

There are many methods for studying community succession (Glenn-Lewin *et al*., 1992; Liu, 1992; Zhang, 1995; Heshmatti and Squires, 1997). In this paper, we used simultaneous sampling investigation methods, that is, succession data were collected simultaneously from different succession stage, and were analyzed with the quantitative classification method (TWINSPAN) and the ordination technique (DCA). This method is known as static succession analysis. Using this study method, the development trends, direction and process of community succession were clearly described. The natural succession of plant community in the modern Yellow River Delta belonged to primary succession without human disturbance. The succession series of plant community in the study area was as follows: saline bare land→ community *S. salsa*→community *T. chinensis*→ grassland. The formation of this succession series was closely related to soil water and salt dynamics. Soil parent material of the modern Yellow River Delta came from the large quantity of sand and mud carried by the Yellow River, which deposited at the mouth of the Yellow River and formed landforms of alluvial plain. Due to the lower altitude, sea tide invaded easily, soil near the coastline has higher content of soil salt and soil water. From coastline to inland, land was gradually rising, groundwater level fell, and amount of soil salt content was decreased. Soil salt content and soil water showed obvious gradient change. Similarly, plant distribution showed obvious rule along with the distribution of soil water and salt content. That is, soil near coastline, which has higher salt content, was bare land, going up from bare land, salt-enduring species *S. salsa* and *T. chinensis* occurred. These two species formed monodominant community or community consisting of both of them. With distance from coastline increasing, rising of altitude and decreasing of soil salt content, the importance of *S. salsa* and *T. chinensis* became lower, the component of perennial grass dominated gradually. The community types dominated by *P. communis*, *I. cylindrica* and *A. littoralis* were developed in suitable area. These community types were the higher stage of natural succession in the modern Yellow River Delta.

The distribution of soil water and salt content were important factors that affect plant community succession of the Delta. In the areas with higher soil salt content, plant community succession was in the lower stage. The succession degree was between 30 and 100; along with decreasing of soil salt content, community succession entered into a higher stage, the species composing the community increased, community structure became more complicated, the succession degrees of community were between 100 and 200, some community's succession degrees had increased to 200~300, which was close to the succession stage of grassland climax.

Shannon-Wiener diversity index is a measure of community diversity and heterogeneity in the species level. It can comprehensively reflect species diversity of the community and degree of individual distribution among species. The results of this paper indicate that indexes of community diversity, richness and evenness in different succession stages of the modern Yellow River Delta increase with the succession progress. That is, the number of plant species increased gradually, the community structure tends to be complex with the succession progress, so, species richness increased significantly. When community succession was close to climax in the community, species diversity index decreased slightly. The above-mentioned character of diversity of different community succession stages is in agreement with the common succession rule.

DCA ordination analysis reflects quite good gradient relation between trends, direction and process of succession and environment (Zhang, 1995; 2000). The DCA first axis represents what stage various quadrats are during the succession process and the gradient relation between succession stage and environment. That is, soil salt content from right to left along DCA first axis decreased gradually, community succession changed also from lower stage to higher stage, species composition increased, community structure tended to be more complex. This illustrates that soil salt content is the important factor that influences plant community succession in the study area.

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References

Baoyin, T.G.T., Liu, M.L., Li, X.L., 2003. The study on dynamics succession of community in degenerated. *Acta Phytoecologica Sinica*, **27**(2):270-277 (in Chinese).

Daubenmire, R., 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. *Ecological. Monographs.*, **22**(4): 301-330. [doi:10.2307/1948472]

Glenn-Lewin, D., Peet, R., Veblen, T., 1992. Succession: Theory and Prediction. Chapman & Hall, London, p.180-190.

Greig-Smith, P., 1983. Quantitative Plant Ecology, 3rd Ed. Blackwell Scientific Publications, London, p.1-31.

Heshmatti, G., Squires, V.R., 1997. Geobotany and range ecology: a convergence of thought? *Journal of Arid Environments*, **35**(3):395-405. [doi:10.1006/jare.1995.0144]

Leendertse, P.C., 1997. Long-term changes (1953-1990) in the salt marsh vegetation at the Boschplaat on Terschelling in relation to sedimentation and flooding. *Plant Ecology*, **132**(1):49-58. [doi:10.1023/A:1009795002076]

Li, W.L., Li, Z.Z., Zhou, Z.X., 2001. A quantitative research on artificial plant community. *Journal of Lanzhou University (Natural Sciences)*, **37**(5):98-104 (in Chinese).

Liu, J.G., 1992. Advance in Modern Ecology. China Science and Technology Press, Beijing, p.69-76 (in Chinese).

Luo, X.S., 1994. Discussion on the plant community succession in Hetian erosion area. *Bulletin of Soil and Water Conservation*, **14**(3):48-51 (in Chinese).

Margalef, R., 1968. Perspective in Ecological Theory. University of Chicago Press, Chicago.

Martínez, M.L., Vázquez, G., Sánchez Colón, S., 2001. Spatial and temporal variability during primary succession on tropical coastal sand dunes. *Journal of Vegetation Science*, **12**(2):361-372. [doi:10.2307/3236850]

Ren, H., Cai, X.A., Rao, X.Q., Zhang, Q.M., Liu, S.Z., 2001. The theory on succession of plant community. *Ecologic Science*, **20**(4):59-67.

Wang, X.P., Jiang, G.M., 2002. Study on classification, distribution and succession of *Pinus massoniana* forest in Guangxi. *Bulletin of Botanical Research*, **22**(2):151-155 (in Chinese).

Zhang, J.T., 1995. Methods in Quantitative Vegetation Ecology. China Science and Technology Press, Beijing, p.97-255 (in Chinese).

Zhang, J.T., 2000. The relationship between environmental decline and the destruction of vegetation in loess plateau. *Journal of Shanxi University (Natural Science Edition)*, (Suppl.):37-41 (in Chinese).

Zhang, J.T., 2005. Succession analysis of plant communities in abandoned cropland in the eastern loess plateau of China. *Journal of Arid Environments*, **63**(2):458-474. [doi:10.1016/j.jaridenv.2005.03.027]