Chin. Geogra. Sci. 2012 Vol. 22 No. 2 pp. 154–166
doi: 10.1007/s11769-011-0475-z
www.springerlink.com/content/1002-0063

Impact Factors on Distribution and Characteristics of Natural Plant Community in Reclamation Zones of Changjiang River Estuary

SUN Yongguang[1, 2], LI Xiuzhen[1], HE Yanlong[1], JIA Yue[1], MA Zhigang[1], GUO Wenyong[1], XIN Zaijun[1]
(*1. State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China; 2. Department of History, Culture and Tourism, Gannan Normal University, Ganzhou 341000, China*)

Abstract: To identify impact factors on the distribution and characters of natural plants community in reclamation area, with survey data from 67 plant quadrats in July 2009, soil properties data from 216 sampling points in April 2009, and TM (30 m) data in 2006, the composition and characteristics of natural plants community in different time of the Fengxian area in the Changjiang (Yangtze) River estuary were analyzed with two-way indicator species analysis (TWINSPAN), multivariate analysis of variance (MANOVA), detrended canonical correspondence analysis (DCCA) and canonical correspondence analysis (CCA). The results show that: 1) The plant communities in the reclaimed area are mainly mesophytes and helophytic-mesophytic transitional communities, showing a gradient distribution trend with the change in reclamation years. Species richness (*MA*), species diversity (*H*) and above-ground biomass also increase with the increase of reclamation years. Nevertheless, they appear to decline slightly in the middle and late reclamation period (> 30 years). 2) With the rise in land use levels, the changes in species richness and species diversity tend to increase at first and then decrease; species dominance (*D*), however, tends to decline; and above-ground biomass increases slightly. 3) The distribution of the plant community is mainly influenced by the following factors: land use levels ($R = 0.55$, $p < 0.05$), soil moisture ($R = 0.53$, $p < 0.05$), soil salinity ($R = 0.43$, $p < 0.05$) and reclamation time ($R = 0.40$, $p < 0.05$).
Keywords: natural plant communities; soil properties; land use patterns; reclamation time; Changjiang River estuary

Citation: Sun Yongguang, Li Xiuzhen, He Yanlong, Jia Yue, Ma Zhigang, Guo Wenyong, Xin Zaijun, 2012. Impact factors on distribution and characteristics of natural plant community in reclamation zones of Changjiang River estuary. *Chinese Geographical Science*, 22(2): 154–166. doi: 10.1007/s11769-011-0475-z

1 Introduction

For centuries, the earth′s surface system has been undergoing changes under the combined influence of natural forces and human activities (Forman, 1995; Zonneveld, 1995; Fu *et al*., 2006). Reclamation is one of the primary means for coastal countries to expand their land territory and alleviate the contradiction between men and land (Li *et al*., 2007). Tidal flat inning and its exploitation have a history of over 1000 years in China (Chen, 2000). The Netherlands, Germany, North Korea, the UK and other countries also have a long history of several hundreds or even about one thousand years in tidal flat inning (Pethick, 2002). Nevertheless, the environmental problems after reclamation are also increasingly evident. The Chinese government has listed the reclamation area among the ecologically vulnerable areas of the coastal land/water ecotone (MEP, 2008), and more attention is being devoted to changes in the environment after reclamation.

There has been a broad discussion on the relationship among vegetation, soil factors and land use patterns (El-Demerdash *et al*., 1995; Byeong and Kim, 1997; Ukpong, 1997; Critchley *et al*., 2002; Abd, 2003; He *et al*., 2009; Yang and Yao, 2009), especially on the relationship between soil and vegetation under the com-

Received date: 2010-12-03; accepted date: 2011-03-25
Foundation item: Under the auspices of Ministry of Education, China (No. 108148), State Key Laboratory of Urban and Regional Ecology (No. SKLURE2010-2-2), National Basic Research Program of China (No. 2010CB951203), Key Research Program of Shanghai Science & Technology (No. 08231200700, 08231200702)
Corresponding author: LI Xiuzhen. E-mail: Landscape2001@sina.com.

bined influence of different control factors in reclamation areas (Byeong and Kim, 1999a; 1999b; 2000). In China, some studies have focused on the vegetation distribution, succession and the effect of various engineering measures on vegetation distribution in the coastal wetland outside reclamation area (Tang and Lu, 2003; Wu *et al*., 2008; Han *et al*., 2009; Huang, 2009; Wang *et al*., 2010). Some scholars found that the distribution and succession of tidal wetlands vegetation were affected mainly by elevation and salinity out of the reclamation area (Huang, 2009). A few studies have focused on the vegetation distribution mechanism in coastal reclamation area. Wang *et al*. (2010) found that the species diversity and cover of plant communities were lower in the area closer to the salt pan in coastal reclamation area. Over-development and construction lead to the declination of plant community productivity, loss of stability balance, block of natural vegetation succession in reclamation areas (Wu *et al*., 2008). Ge *et al*. (2005) found that there was a significant secondary succession of the plant community in the reed marsh of Chongming Dongtan, Shanghai, China due to the soil drought and salinization caused by artificial drainage.

In conclusion, considerable studies have been conducted concerning the ecological impacts of reclamation, most of which concentrated on the vegetation distribution change after reclamation and the effect of reclamation on vegetation (Han *et al*., 2009; Huang, 2009). However, the relationships of land use types and reclamation time with the structure of plant communities after reclamation were rarely studied. In particular, there were even less studies on the contribution of natural and human factors to vegetation distribution in reclamation areas. The ecological functions of vegetation and the key impact factors along with reclamation time have also not been investigated. Since the founding of the People′s Republic of China in 1949, the total area of land reclaimed from the sea has reached 12 000 km^2 (Chen, 2000). Due to lack of studies on the ecological impact of reclamation, the corresponding relationship between plant communities and impact factors has not been established yet.

This study analyzed the composition and characteristics of natural plant community in different reclamation zones of the Fengxian area in the Changjiang (Yangtze) River estuary, and identified the contributions of human factors (i.e. land use types and reclaimed time) and natural factors (i.e. soil physico-chemical properties and altitude) to the changes of the plant community. Our hypotheses are: 1) The composition and characteristics of the plant community show gradient trends among zones with different reclamation times; 2) different land-use levels may influence the spatial differentiation of the plant community; and 3) the influencing degree of both natural and artificial factors on the plant community can be identified through statistical analysis. This study will contribute to the understanding of the interaction between ′pattern and process′ of landscape ecology, and provide a scientific basis for the management of the reclamation area.

2 Materials and Methods

2.1 Study area

The Fengxian reclamation zone (30°48′–30°53′N, 121°30′–121°43′E) of Shanghai in the Changjiang River estuary was selected as the study area. It stretches 6 km from south to north and 20 km from east to west, with a coastline of 20 km (Fig. 1). The study area belongs to the northern-subtropical monsoon climate, with four distinctive seasons—short spring and autumn and long summer and winter. The average annual temperature is 16.8℃, with 27.8℃ in July and 3.6℃ in January. The annual precipitation is around 1100 mm, of which 80% concentrates between June and October. Summer is hot and humid, with plenty of thunderstorms and rainfall, while winter is cold. Intensive sunshine, high temperature and high rainfall are all found in summer, which is beneficial to multiple-cropping agricultural production.

From 1853 to 1900, in the Qing Dynasty, the silt tidal flat was enclosed with a dyke and reclaimed in the study area. After founding of the People′s Republic of China, further reclamation was conducted by building dams at different periods, including the Renmin dam of 1960, the Tuanjie dam of 1974, the Jinhui dam of 1979, and the Blue Sea and Gold Sand dam of 2006 (Fig. 1). Thus the study area was divided into five reclamation zones (Fig. 1) based on reclamation times (Jin, 2007). Land-use types and vegetation functions in the area have clearly changed, providing an ideal place to study the relationship between land-use types, soil environment and vegetation.

2.2 Data collection

2.2.1 Land use data

The vector data of land use types were derived from the

TM (30 m) data of the Changjiang River estuary in 2006, with interactive interpretation in Erdas 9.2 and GIS 9.2 (Table 1). According to Wang *et al.* (2001), land use levels were determined for different land use types (Table 1). TM interpretation accuracy was verified with the data from 216 sampling points of field survey (Fig. 1). Precision for open water, aquaculture pond, mud flat and greenhouse land was over 92%. Precision for dry

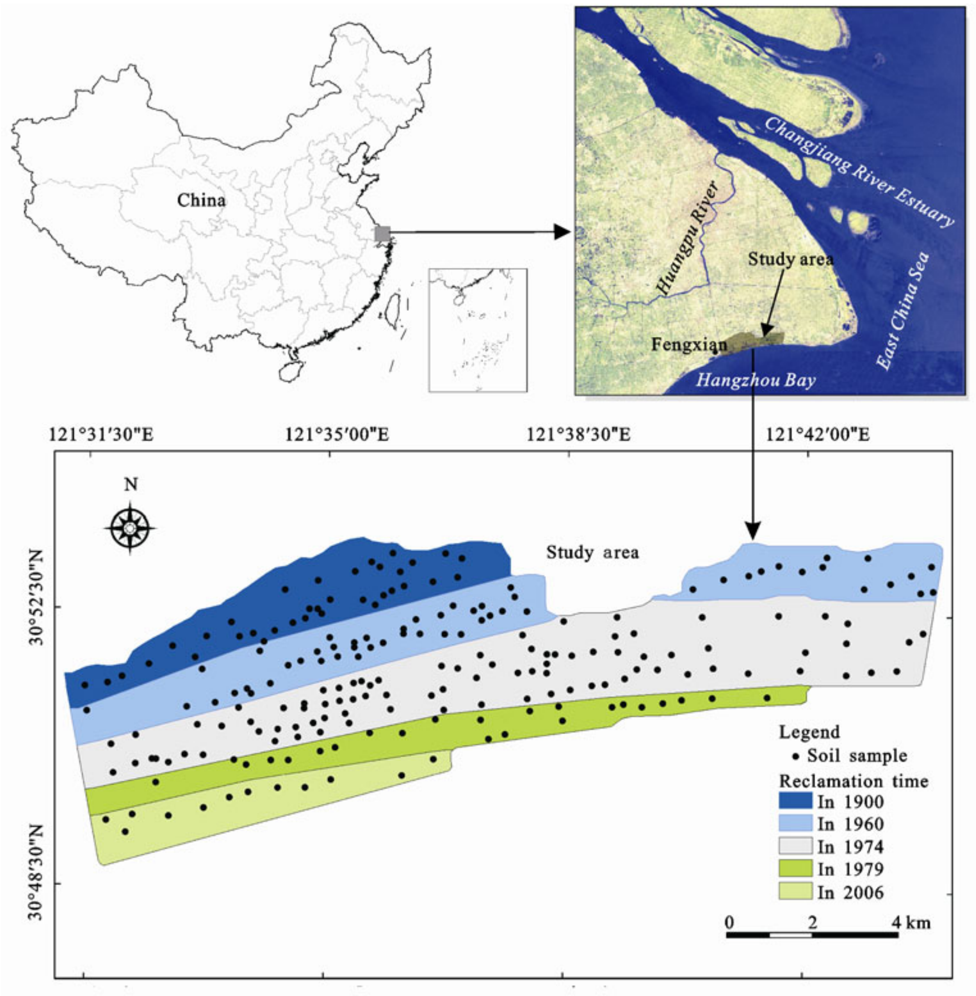


Fig. 1 Map of study zones showing sampling points for soil

Table 1 Land use classification and description in reclamation zones of Changjiang River estuary

Land use level	Land use type	Description
1	Unutilized land	Unutilized tillage and abandoned fields
	Mudflat	Bare land with seawater pumped in reclamation area
2	Grassland	Reed marsh tidal flats, pasture and grasslands in parks
	Open water	Rivers, lakes, irrigation canals and non-cultured water surfaces
	Forest land	Forest along fields, forest park and sparse woodland
	Aquiculture pond	Ponds for feeding fish, shrimps and crabs
3	Orchards	Land for perennial crops such as fruits and flowers
	Dry land	Land for planting corn, cotton, winter wheat, and other crops without irrigation
	Irrigated land	Non-greenhouse land for the planting of various seasonal vegetables
	Greenhouse land	Land covered by greenhouses year-round
4	Built-up land	Reclamation dam, residential land, built-up land for industrial and mining enterprises

Source: Wang *et al.*, 2001

land, paddy field, irrigated land, forest land, grassland and orchards was over 85%, while that for built-up land and unutilized land was over 90%. Finally, the map of plant quadrats distribution was overlaid with a land use map to obtain the background of land use levels (Fig. 2).

2.2.2 Soil data

Soil properties data were collected from 216 sampling points (Fig. 1) in five reclamation zones in April 2009. According to the extent of the study area (20 km × 6 km), Random Uniform Grid method was used for sampling. Each grid had a size of 0.5 km × 0.5 km, and GPS was used for positioning. Soil samples were collected from depths of 0–10 cm and 10–20 cm and mixed up. The mixture samples were placed in zip lock bags, and relevant information (i.e. soil types, vegetation and land use types) was also carefully recorded. All samples were air-dried under normal temperature conditions.

Indices of soil physico-chemical properties should be able to demonstrate soil quality and the particularity of coastal reclamation. Therefore the indices including soil compaction, soil particle size, soil organic matter, available phosphorus, ammonia nitrogen, nitrate nitrogen, soil salinity, soil moisture and pH were selected. Soil salinity, moisture, pH and soil compaction were measured with salt-water apparatus (SDI-12/RS485 made in Australia) and a soil compaction meter (TJSD-750 made in China). Soil particle size was obtained with a laser particle size analyzer (LS 100Q made in the USA). Soil organic matter, available phosphorus, ammonia nitrogen and nitrate nitrogen were measured in the laboratory with Soil Nutrient-Temperature-Humidity Instruments (TFW-VI made in China).

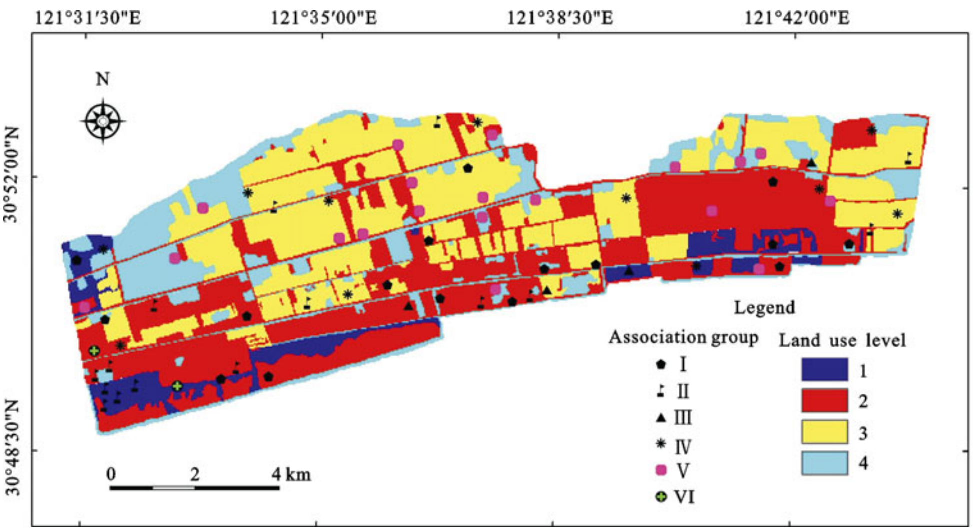
2.2.3 Plant data

Plant data were collected from 67 quadrats (Fig. 2) in five reclamation zones in July 2009. Since trees in the reclamation area were mostly planted, they were not considered in this study. Shrubs and herbs naturally growing in the quadrats were recorded about their names, abundances, coverage, heights, frequencies and aboveground biomass (fresh weight). Latitude, longitude and elevation of each sampling quadrat were also recorded.

2.3 Methods

2.3.1 Analysis of impact factors on plant community composition

Two-Way Indicator Species Analysis (TWINSPAN) was used to classify the plant community in the study area based on the importance values (relative height + relative frequency + relative coverage) of species of all quadrats (Hill, 1979). The TWINSPAN analysis was performed using PC-ORD 4.0. The classification matrix



Ⅰ: *Robinia pseudoacacia* + *Conyza bonariensis* + *Phragmites australis* + *Arundo donax*; Ⅱ: *Robinia pseudoacacia* + *Phragmites australis* + *Medicago polymorpha* + *Conyza bonariensis*; Ⅲ: *Robinia pseudoacacia* + *Cayratia japonica* + *Solanum nigrum* + *Paspalum paspaloides*;Ⅳ: *Setaria viridis* + *Chenopodium album* + *Robinia pseudoacacia* + *Humulus scandens*; Ⅴ: *Robinia pseudoacacia* + *Setaria viridis* + *Humulus scandens* + *Conyza bonariensis*; Ⅵ: *Erigeron annuus* + *Typha angustifolia* + *Paspalum paspaloides* + *Digitaria sanguinalis*; 1. Unutilized land, Mudflat; 2. Grassland, Open water, Forest land, Aquiculture pond; 3. Orchards, Dry land, Irrigated land, Greenhouse land; 4. Built-up land

Fig. 2 Spatial distribution for different association groups in study area and distribution of land use levels is $P \times N$, where P is the number of quadrats (67) and N was the number of species (50).

Detrended Canonical Correspondence Analysis (DCCA) was used to analyze the relationship between plant community composition and impact factors (He *et al.*, 2009). DCCA requires two data matrices. One is the data matrix $P \times N_1$ of the importance value of species, and the other is $P \times N_2$ of land use type (here land use levels were used), reclamation time, soil properties and elevation, where N_2 is the impact factors, including soil compaction, soil particle size, soil moisture, soil salinity, soil organic matter, soil ammonia nitrogen, soil nitrate nitrogen, available phosphorus, soil pH value, reclamation time, land use levels and elevation. The appropriate fitted model based on the semi-variance analysis was selected using GS+ 5.0, and the spatial interpolation analysis was performed on soil properties data with the help of GIS 9.2. The background of soil properties for each plant quadrat was finally derived through overlay analysis in GIS 9.2.

2.3.2 Analysis of impact factors on plant community characteristics

The following three indices reflecting the characteristics of plant community were selected:

(1) Species richness: Margalef index (MA) was adopted, which is expressed as (Ren, 1998):

$$MA = (S - 1) / \ln N \quad (1)$$

where S is the number of species; and N is the number of individuals of all species in a community.

(2) Species diversity: Shannon-Weaver index (H) was used, which can be calculated as (Ren, 1998):

$$H = -\sum P_i \ln P_i \quad (2)$$

where $P_i = n_i / N$, n_i is the importance value of species i, and N is the sum of the importance value of all species in a community.

(3) Species ecological dominance: Simpson dominance index (D) was used, which is expressed as:

$$D = \sum (n_i / N)^2 \quad (3)$$

where n_i is the number of species i in a community; and N is the number of all individuals in a community (Ren, 1998).

Multivariate analysis of variance (MANOVA) was adopted to determine whether there was a significant difference among plant communities in different reclamation zones. Canonical Correspondence Analysis (CCA) was used to analyze the relationships between plant community indices and impact factors. CCA requires two data matrixes. One is the plant community indices, and the other is factor variables (land use, reclamation time, elevation and soil properties) (Jia *et al.*, 2007). DCCA and CCA were performed with Canoco 4.5, and MANOVA analysis was done with SPSS 17.0.

3 Results

3.1 Analysis of plant community composition

Fifty species were found in 67 investigated quadrats (Table 2), which belong to 50 genera in 20 families, including Gramineae (15 species), Compositae (8 species), Amarathaceae (2 species), Chenopodiaceous (1 species), Leguminosae (4 species), Linaceae (1 species), Convolvulaceae (1 species), Portulacaceae (1 species), Polygonaceae (3 species), Ranunculaceae (1 species), Typhaceae (1 species), Rubiaceae (1 species), Solanaceae (2 species), Vitaceae (1 species), Scrophulariacea (1 species), Moraeeae (1 species), Cypercaceae (3 species) and Euphorbiaceae (1 species), Triaenophora (1 species), Polygonaceae (1 species). The main water ecotypes are mesophytes, accounting for 78% of the total species. Helophytes (16%) and hygrophytes (4%) have much less number of species (Table 2). Six plant association groups were classified for the study area in TWINSPAN (Table 2).

Association Group I: *Robinia pseudoacacia* + *Conyza bonariensis* + *Phragmites australis* + *Arundo donax*. It was a helophytic-mesophytic association group that included 15 quadrats (S6, S8, S12, S16, S25, S38, S18, S21, S33, S37, S45, S48, S49, S51, S59) (Fig. 2), and was mainly distributed in the area at the reclamation periods of 3, 30 and 35 years (years = sampling time (2009) – reclamation time) (Fig. 1). Land use types were mainly aquaculture ponds and open water. There were 14 companion species in this transitional association group, which included 11 species of mesophytes and 3 species of hygrophytes (Table 2).

Association Group Ⅱ: *Robinia pseudoacacia* + *Phragmites australis* + *Medicago polymorpha* + *Conyza bonariensis*. This was a helophytic-mesophytic transitional association group including 15 quadrats (S1, S2, S3, S4, S7, S9, S10, S11, S20, S23, S27, S53, S55, S66, S67) (Fig. 2), mainly distributed in the reclamation zone of 3 years, and scattered in the reclamation zone of 30

Table 2 Ecotype and importance values of main species for different association groups in study area

Species name	Ecotype	Group I	Group II	Group III	Group IV	Group V	Group VI
Phragmites australis (Cav.) Trin. ex Steud.	He	**8.34**	**5.64**	0.31		0.62	0.57
Arundo donax Linn.	He	**7.85**	1.56		0.56	1.09	
Setaria viridis (Linn.) Beauv.	M	0.89	1.49	0.84	**7.62**	**9.30**	
Eleusine indica (Linn.) Gaertn.	M		1.13	0.26	1.41	3.15	
Leptochloa mucronata (Michx.) Kunth	M				1.68	0.77	
Eclipta prostrata (Linn.) Linn.	M				0.88	1.01	
Alternantheraphiloxeroides (Mart) Griseb.	H	0.87	0.75		1.26	0.85	
Sonchus oleraceus Linn.	M		0.71		0.43	1.00	
Chenopodium album Linn.	M			0.55	**3.62**	2.73	
Paspalum paspaloides (Michx.) Scribn.	M	0.45	0.16	**0.93**	0.20		**0.80**
Digitaria sanguinalis (L.) Scop.	M		0.94	0.58	0.18	0.64	**0.61**
Robinia pseudoacacia var. *pseudoacacia* (Linn) Linn.	M	**11.79**	**7.58**	**2.72**	**3.22**	**11.29**	
Erigeron annuus (L.) Pers.	M	0.40	2.40	0.39	2.18	0.45	**2.09**
Aster tataricus L. f.	M	0.06	0.05			0.07	
Pueraria lobata (Willd.) Ohwi	M		3.32			0.53	
Conyza bonariensis (L.) Cronq.	He	**8.41**	**4.24**		1.70	**6.20**	
Achnatherum splendens (Trin.) Nevski	M		0.75				
Linum usitatissimum Linn.	M				1.38	0.35	
Xanthium sibiricum Patr. Ex Widd.	M					0.14	
Cuscuta europaea Linn.	M		0.69				
Portulaca oleracea Linn.	M				0.19	0.10	
Rumex acetosa L.	M				0.32		
Polygonum hydropiper L.	He				0.40	0.55	
Batrachium bungei (Steud.) L. Liou	He			0.12			
Polypogon fugax Nees ex Steud.	M		0.18				
Typha angustifolia L.	H	0.55				1.35	**0.73**
Artemisia sieversiana Ehrhart ex Willd.	M	0.92	1.59			0.69	
Paederia scandens (Lour.) Merr.	M	0.80		0.14	0.27	2.40	
Amaranthus tricolor Linn.	M				0.36	1.48	
Medicago polymorpha L.	He		**4.61**		0.53	0.43	
Solanum nigrum L.	M			**1.02**	2.06	1.24	
Cayratia japonica (Thunb.) Gagnep.	M	2.12		**1.96**	0.90	1.41	
Veronica serpyllifolia L.	M					0.06	
Humulus scandens (Lour.) Merr.	M	2.49	0.79	0.71	**2.37**	**7.55**	
Festuca sinensis Keng.	M		0.13		0.11		
Saussurea japonica (Thunb.) DC.	M	0.16	0.18	0.70	0.17	0.47	
Elymus dahuricus Turcz.	He			0.19			
Carex tristachya Thunb.	He						0.15
Carex scbrifolia Form.	He		0.08		0.05		0.53
Rumex japonicus Houtt.	M	0.13	3.00		0.18	1.74	0.27
Urena lobata Linn. var. *scabriuscula* (DC.) Walp.	M						0.07
Cyperus microiria Steud.	M						0.18
Cynodon dactylon (L.) Pers	M			0.42	0.10		
Herba Plantaginis L.	M		0.09				
Mimosa pudica Linn	M	0.15			0.29		
Physalis alkekengi Linn.	M				0.17	0.16	
Convolvulus arvensis L.	M					0.08	
Poa annua L.	H	0.20		0.17	1.12		
Daetyloctenium aegyptium (L.) Beauv	M				0.15	0.29	
Euphorbia esula Linn	M				0.03		

Notes: M, mesophyte; H, hygrophyte; He, helo-phyte; dominant species are highlighted years. This association group mainly reflected the characteristics of shrub-grass vegetation in the early period of reclamation, and gave priority to helophytic salt-tolerant vegetation. This group prefered the area with open water, grassland and swamps. There were 20 main companion species (Table 2), which included 17 species of mesophytes, 1 species of helophyte, and 2 species of hygrophyte.

Association Group Ⅲ: *Robinia pseudoacacia* + *Cayratia japonica* + *Solanum nigrum* + *Paspalum paspaloides*. It was a mesophyte association group, including four quadrats (S14, S17, S46 and S58), and were mainly distributed in the reclamation zone of 30 years with aquaculture ponds (Fig. 2). The shrub-grass vegetation has gradually transited from helophytic to mesophytic after reclamation of 30 years. There were 13 main companion species, including 9 species of mesophytes, 3 species of helophytes and 1 species of hygrophyte.

Association Group Ⅳ: *Setaria viridis* + *Chenopodium album* + *Robinia pseudoacacia* + *Humulus scandens.* This was also a mesophyte association group including 11 quadrats (S19, S22, S41, S42, S44, S47, S52, S56, S57, S63, S65) (Fig. 2), and was mainly distributed in the area after being reclaimed for more than 35 years and 109 years, which indicated that there was no obvious change in the composition of the plant community in the area being reclaimed for more than 30 years. This association group was mainly distributed in arable land. There were 29 companion species, including 22 species of mesophytes, 5 species of helophytes, and 2 species of hygrophytes.

Association Group Ⅴ: *Robinia pseudoacacia* + *Setaria viridis* + *Humulus scandens* + *Conyza bonariensis*. This is another mesophyte association group, which included 20 quadrats (S13, S15, S26, S28, S29, S30, S31, S32, S34, S35, S36, S39, S40, S43, S50, S54, S60, S61, S62 and S64) (Fig. 2), mainly distributed in the area being reclaimed for 49–109 years. However, there was no distribution in the area being reclaimed for 3 years, and it was occasionally found in the area being reclaimed for 30 years. This association group was mainly distributed in the farming area (Fig. 2). There were 29 companion main species, including 23 species of mesophytes (Table 2), 4 species of helophytes and 2 species of hygrophytes.

Association Group Ⅵ: *Erigeron annuus* + *Typha angustifolia* + *Paspalum paspaloides* + *Digitaria sanguinalis*. This was a mesophyte association group, including two quadrats in the area being raclaimed for 30 years and 35 years. For this association group, land use types were built-up land and farmland. There were 6 main companion species (Table 2), including 3 species of mesophytes and 3 species of helophytes.

Based on TWINSPAN analysis, most of the association groups gave priority to mesophytes, but gave priority to helophyte-mesophyte transitional plants in the early period after reclamation (3 years). The distribution of association groups was influenced by land use types and levels.

3.2 Characteristics of plant community in different reclamation time

The characteristics of the plant community can reflect vegetation functions and ecological niche. In our research, the characteristics of plant community (species richness *MA*, species diversity index *H*, species dominance index *D* and aboveground biomass) were supposed to be different among different reclamation zones. Therefore 67 quadrats were divided into 5 groups based on different reclamation time, and then the indices of plant community were analyzed with MANOVA (Table 3).

The characteristic indices of plant communities at different reclamation zones demonstrate significant differences ($p < 0.05$) (Table 4). The LSD multiple range test was performed to test the significant difference in species richness (*MA*) and species diversity (*H*) in the early reclamation period (< 49 years). No significant difference was detected in the zones with reclamation time shorter than 50 years (Table 3). Moreover, with the increase of reclamation time, species richness and diversity tended to increase. Above-ground biomass showed significant difference among the 5 different reclamation zones, where early reclamation stages (≤ 30 years) and middle-late reclamation stages (> 30 years) had significant differences. Aboveground biomass tended to slightly increase with the increase of reclamation time (Table 3). Species dominance (*D*) showed no significant differences among zones of different reclamation years.

3.3 Characteristics of shrub-grass community among different land-use levels

Among different land-use levels, no significant difference was found for species dominance (*D*) and

Table 3 Descriptive statistics of shrub-grass vegetation in different reclamation zones

Index	Time (yr)	N	Mean	Median	±S.D.	Min	Max	Skewness	Kurtosis
Species richness (Margalef index *MA*)	3	8	1.04a	1.15	0.44	0.38	1.77	0.01	–0.08
	30	13	1.25a	1.18	0.54	0.55	2.13	0.42	–0.95
	35	19	1.16a	1.08	0.50	0.46	2.04	0.45	–0.70
	49	19	1.39a	1.36	0.56	0.30	2.57	0.34	0.08
	109	8	2.11b	2.28	0.68	0.95	2.92	–0.56	–0.83
Species diversity (Shannon-Weaver index *H*) (bit)	3	8	1.63a	1.71	0.34	1.06	2.07	–0.52	–0.67
	30	13	1.72a	1.94	0.38	0.96	2.16	–0.94	–0.04
	35	19	1.68a	1.62	0.46	0.69	2.42	–0.22	–0.04
	49	19	1.82a	1.88	0.42	0.69	2.43	–0.96	1.39
	109	8	2.20b	2.34	0.34	1.51	2.45	–1.46	1.21
Species dominance (Simpson dominance index *D*)	3	8	0.40a	0.41	0.10	0.21	0.52	–0.89	0.76
	30	13	0.47a	0.38	0.24	0.18	0.80	0.37	–1.75
	35	19	0.43a	0.38	0.15	0.22	0.81	1.09	1.09
	49	19	0.46a	0.41	0.18	0.22	0.86	0.93	0.18
	109	8	0.41a	0.31	0.22	0.19	0.69	0.52	–1.99
Above-ground biomass (kg/m^2)	3	8	1.90a	1.70	0.94	0.55	3.70	0.80	1.54
	30	13	2.60a	2.40	1.10	0.72	4.20	0.03	–1.18
	35	19	5.10b	3.20	4.00	1.60	10.00	1.23	0.22
	49	19	4.20ab	2.60	3.60	1.00	14.00	1.85	3.22
	109	8	3.40ab	3.00	1.50	1.90	6.10	0.82	–0.52

Notes: a, b and c following the mean values indicate statistical separation, with columns in MANOVA followed by LSD; the mean difference is significant at the level of 0.05

Table 4 Results of multivariate tests (MANOVA) for plant plots of five reclamation zones

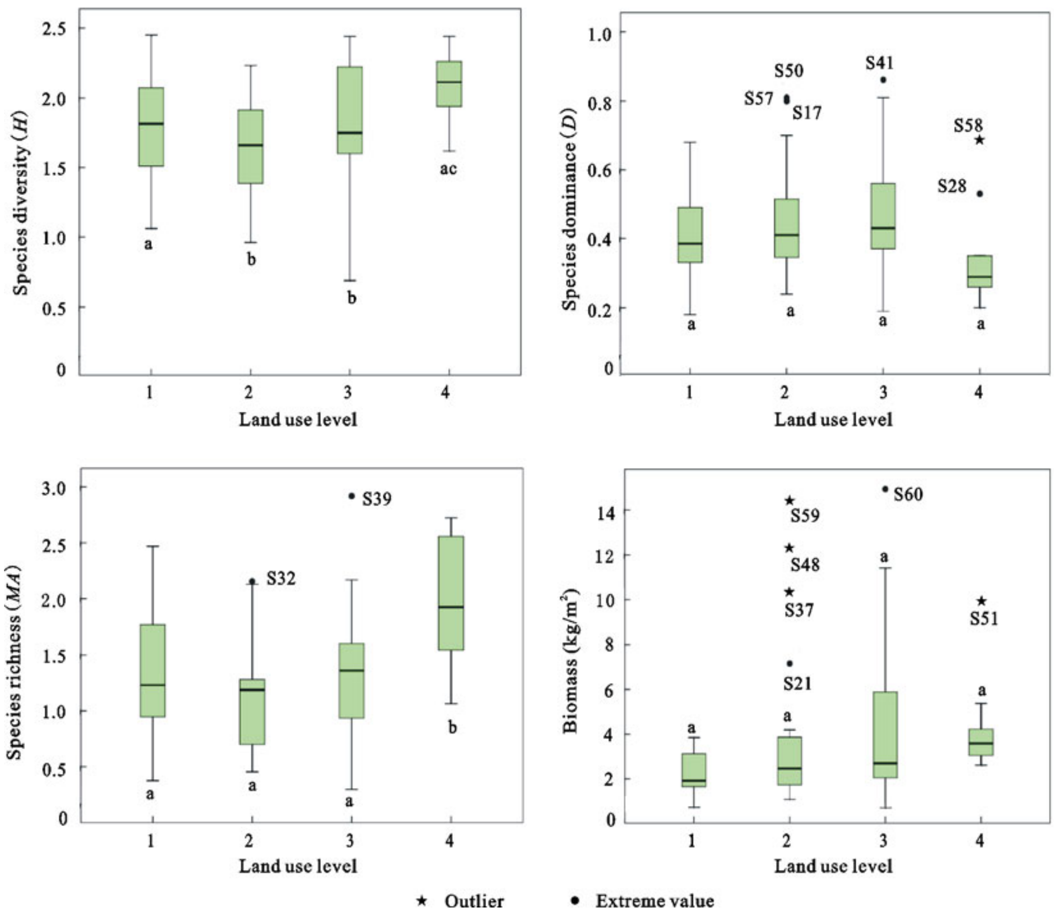
	Test	Value	*F*	Hypothesis *d. f.*	Error *d. f.*	Sig.
Time	Pillai′s trace	0.517	1.810	20.000	244.000	0.020
	Wilks′ lambda	0.546	1.936	20.000	193.314	0.012
	Hotelling′s trace	0.720	2.034	20.000	226.000	0.007
	Roy′s root	0.514	6.276*	5.000	61.000	0.000

Note: Statistic is an upper bound on *F* that yields a lower bound on significance level

aboveground biomass. Species diversity and richness, however, showed different trends. Through LSD test, we found that *MA* had a significant difference among land use levels 2, 3 and 4. With the increase in land-use level, *H* first increased and then decreased (Fig. 3). At the early reclamation stage (3 years), the flora was mainly under natural succession due to low artificial interference, and hence *H* was relatively high. However, when land use types were changed into built-up and transportation land, the natural vegetation once again grew with natural succession, and its species diversity also increased. *MA* had significant differences among different land-use levels, and its growth process was similar to that of *H*. Therefore, changes in land use levels will contribute to the changes in plant community.

3.4 Impact factors of association group distribution

In order to quantitatively examine the influence of reclamation time, land use levels and soil factors on the association group distribution in the reclamation area, DCCA was performed in this study. Soil physical-chemical factors, land-use levels, reclamation time and elevation were indicated by the connections with an arrow lines (Fig. 4). The lengths of the arrow lines represent the relationships between the association group distribution and the impact factors, the quadrants position of the arrows reflect the positive and negative cor-relations between the impact factors and ordination Axes,



S*i* is the number of plant quadrats; a, b, c show significance difference at $p < 0.05$ (LSD)

Fig. 3 Box chart of indices of shrub-grass vegetation in different land use levels

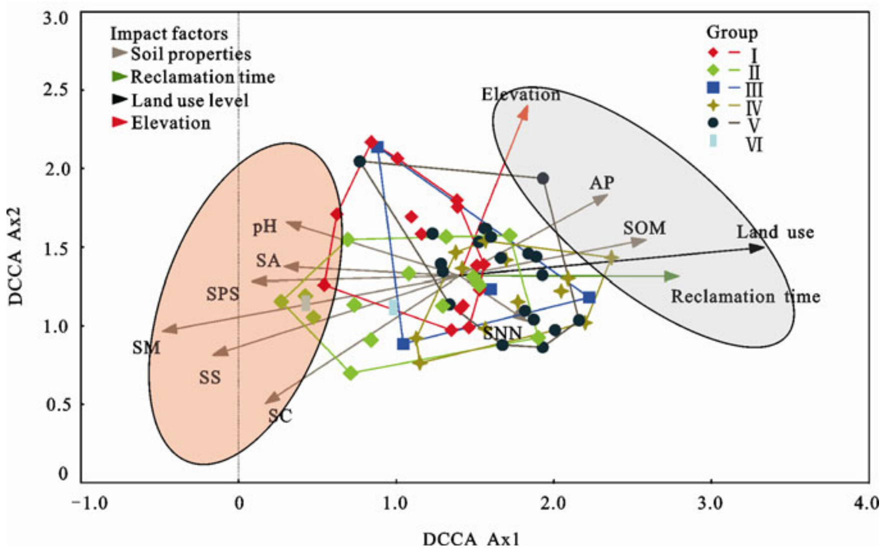
and the angle between the arrow lines and ordination axes indicates the closeness of the correlation of this factor and ordination Axes.

There are some overlaps among the spatial distribution of different association groups (Fig. 4). Nevertheless, the impact factors vary among different association groups. The mesophyte association groups (III, IV, V and VI) were mainly influenced by soil organic matter, available phosphorus, nitrate nitrogen, reclamation time, land use types and elevation, while the helophytic-mesophytic association groups (I, II) were mainly affected by soil limitation factors (soil moisture, soil salinity, soil particle size, soil compaction and pH).

Impact factors of association groups (Elliptical circles enclosing impact factors; Test of significance of first canonical axis: eigenvalue = 0.227, F = 2.856, p = 0.0120; test of significance of all canonical axes: Trace = 0.958, F = 1.209, p = 0.0140) represent the correla-tions of the two groups with Ax1 and Ax2 of DCCA (Fig. 4): 1) factors that showed a positive correlation with ordination axes, of which the influencing degrees on the distribution of association groups were as follows: land use level (R = 0.55, $p < 0.05$) > reclamation time (R = 0.40, $p < 0.05$) > soil organic matter (R = 0.33, $p < 0.05$) > available phosphorus (R = 0.26, $p < 0.05$) > nitrate nitrogen (R = 0.15, $p < 0.05$) > elevation (R = 0.09, $p < 0.05$); 2) factors that showed a negative correlation with ordination axes, of which the influencing degrees on the distribution of association groups were as follows: soil moisture ($|R|$= 0.53, $p < 0.05$) > soil salinity ($|R|$= 0.43, $p < 0.05$) > soil particle size ($|R|$= 0.38, $p < 0.05$) > soil compaction ($|R|$= 0.33, $p < 0.05$) > soil nitrate nitrogen ($|R|$= 0.32, $p < 0.05$) > pH ($|R|$= 0.32, $p < 0.05$). Land use levels, soil moisture, salinity, reclamation time and soil organic matter were the key impact factors on the distribution of association groups.

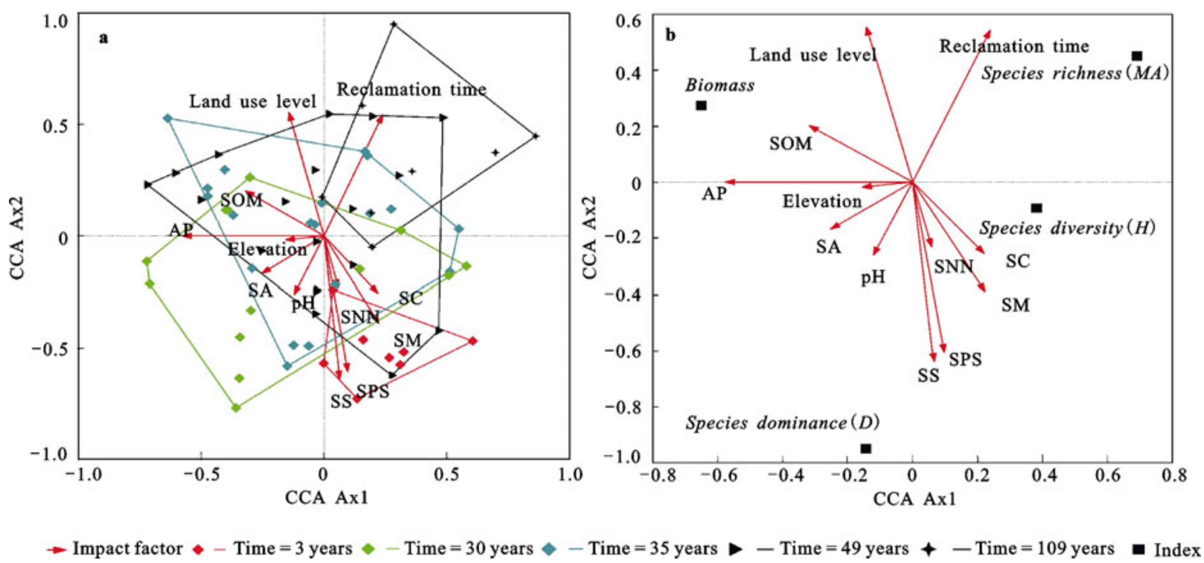
3.5 Impact factors of vegetation indices

CCA analysis can reflect the relationship between plant community indices and soil physico-chemical factors, reclamation time and land use levels. The correlation between vegetation indices and soil limitation factors (soil moisture, soil salinity, soil particle size and soil compaction) was strong (Fig. 5a) in the early reclamation stage (3 years). The vegetation indices were mainly influenced by reclamation time, land use levels, soil organic matter, available phosphorus and other soil fertility factors at the middle-late reclamation stage (> 30 years). CCA ordination proved that soil salinity (R = 0.31, p < 0.05), reclamation time (R = 0.30, p < 0.05) and land use level (R = 0.31, p < 0.05) were the key factors that influence vegetation characteristics. The



I: *Robinia pseudoacacia* + *Conyza bonariensis* + *Phragmites australis* + *Arundo donax*; II: *Robinia pseudoacacia* + *Phragmites australis* + *Medicago polymorpha* + *Conyza bonariensis*; III: *Robinia pseudoacacia* + *Cayratia japonica* + *Solanum nigrum* + *Paspalum paspaloides*; IV: *Setaria viridis* + *Chenopodium album* + *Robinia pseudoacacia* + *Humulus scandens*; V: *Robinia pseudoacacia* + *Setaria viridis* + *Humulus scandens* + *Conyza bonariensis*; VI: *Erigeron annuus* + *Typha angustifolia* + *Paspalum paspaloides* + *Digitaria sanguinalis*; SOM: soil organic matter; SNN: soil nitrate nitrogen; SA: soil ammonium nitrogen; SM: soil moisture; SPS: soil particle size; AP: available phosphorus; SS: soil salinity; SC: soil compaction

Fig. 4 Ordination of plant quadrats of different association groups and impact factors on first two axes of DCCA



SOM: soil organic matter; SNN: soil nitrate nitrogen; SA: soil ammonium nitrogen; SM: soil moisture; SPS: soil particle size; AP: available phosphorus; SS: soil salinity; SC: soil compaction; quadrats communities were identified by reclamation time (3, 30, 35, 49, 109 years); irregular shapes enclosing quadrats with different coloured lines represent correlations of the groups with Ax1 and Ax2 or impact factors of CCA, F = 8.531 by test, p < 0.05

Fig. 5 Ordination of plots and impact factors (a) and vegetation indices and impact factors (b) for first two axes of CCA interaction between different characteristic indices in a community and each impact factor was also not all the same (Fig. 5b). Species richness (*MA*) was positively correlated with reclamation time. The above-ground biomass had the highest correlativity with soil organic matter, followed by land use levels and available phosphorus. The species diversity index (*H*) was influenced by both reclamation time and soil limitation factors (soil compaction and moisture). The dominance index (*D*) showed a positive correlation with soil limitation factors, while it was negatively correlated with reclamation time, land use levels and soil organic matter.

4 Discussion

The effects of mud flat reclamation on vegetation distribution and functions are reflected in several aspects. The seawall building time, the distance from the seawall, land use types and soil physico-chemical factors affect species diversity and distribution to different degrees (Shen *et al*., 2006). However, there are still some questions that deserve to be discussed.

(1) Plant community has gradually undergone a transition from salt-marsh community to mesophytic community after reclamation, and tended to show a gradient change with increasing reclamation time. In the early reclamation period, salt-marsh plant communities and transitional communities were dominant. However, zonal plant communities of mesophytes became dominant and reached the steady-state, with increased species diversity and richness, in the middle-late reclamation period (> 30 years). This result was in line with previous results (Shen *et al*., 2006; He *et al*., 2009). Although the aboveground biomass, species diversity and richness of the plant community tended to increase with increasing reclamation time, they decreased in the middle reclamation period (30–49 years), which was mainly influenced by the mono-crop planting system (Shen *et al*., 2006). Succession of plants is not always positive in reclamation area, and will also appear repeatedly under human interference. Therefore, how to strengthen protection and restoration is essential to the sustainable development of ecological environment after reclamation.

(2) The quantification of the relationship between the variation mechanism and impact factors of a plant community after reclamation was the focus of this study. The relationship between plant and soil properties had been studied on the west coast of Korea (Byeong and Kim, 1997), and soil moisture was found to be the key factor for plant distribution. Huang (2009) found that elevation and salinity were key factors for plant distribution. But, few researches had been done on human factors. We found that land use types, soil moisture, soil salinity, reclamation time and soil organic matter were the key factors that affected the distribution of vegetation association groups in different reclamation zones, of which human factors are the most important. We also found that impact factors for the variation of vegetation characteristic indices were not all the same. Vegetation was mainly affected by soil limitation factors (soil particle size, salinity, moisture and compaction) in the early period after reclamation, and the influence from soil salinization was relatively high. However, reclamation time, land use levels, organic matter, available phosphorus and other factors affected the vegetation indices during the middle-late period (> 30 years), which indicated that vegetation was mainly affected by human activities and soil fertility factors when soil salinity gradually decreased at this stage. The study shows that different therapeutic measures should be taken for the restoration and protection of plants in different periods after reclamation. For example, soil salinization is the most important problem in the early period (0–10 years), while after 20–30 years, human activities should be taken seriously. Thus, good planning is important to ensure sustainable development of the ecological environment.

(3) Different land use types also have a certain effect on the composition and characteristics of plant community (Li, 2004). The effect was, however, rarely quantified. In this study, we analyzed the distribution and characteristics of the plant community under different land-use levels. With the constant reclamation and crop planting, however, species diversity decreased, which was in line with the results of a previous study (Shen *et al*., 2006). The study results could contribute to the management of vegetation in reclamation zones. For example, salt pan is not unfavorable to increase vegetation diversity (Wang *et al*., 2010), people should reduce the proportion of salt pan during the development of the reclamation areas, and appropriately increase the proportion of ecological land-use types (forest, grassland and so on). Land use structure can be adjusted according to species indicators if we wish to maintain relatively

high species diversity or low soil salinity.

5 Conclusions

The study shows that the plant communities in the reclaimed area are mainly mesophytes and helophytic-mesophytic transitional communities, showing a gradient distribution trend with the change in reclamation years. Species richness, species diversity and above-ground biomass also increase with the increase of reclamation years. The distribution of the plant community is mainly influenced by the following factors: land use levels, soil moisture, soil salt and reclamation time.

Although the relationship between vegetation indices and impact factors were quantified in the study, there were some limitations that might affect the precision of the quantification. Firstly, the reclamation area was mainly affected by human activities, and dominated by farm land, breeding ponds and orchards. Therefore natural vegetation was quite limited. In this study, the quadrats were mostly located at the edges of different land use types, to reflect the growth status of natural vegetation as much as possible, which may be also the key reason to lead to outliers and extreme values occurring from survey data of quadrats. The number of recorded species could, however, still be much less than that of the potential status. Secondly, the formulation of specific management policies of land use and the effects of different policies on vegetation were not considered in this study. Therefore the inherent correspondence between the natural system and human activities in reclamation zones need further exploration.

Since the study area is part of Shanghai Municipality, which has a high population density, conclusions drawn concerning this area might not be applicable in other reclamation zones. The methods adopted to quantify the contribution of different factors to the plant community in the reclamation zones are, however, applicable in similar studies.

Acknowledgements

The authors would like to thank Prof. Ülo Mander from Department of Geography, Institute of Ecology & Earth Sciences, University of Tartu, Estonia for improving the English of the manuscript, and also thank Prof. Zhou Yunxuan from State Key Laboratory of Estuarine and Coastal Research, East China Normal University for his help with TM data collection in the study area.

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