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Effects of landscape evolution stages on soil properties distribution in Yancheng National Nature Reserve, China

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Abstract

A typical wetland in the core area of Yancheng National Nature Reserve was chosen as study area. Using three periods of remote sensing images in 1992, 2002 and 2011, different successional stages of landscape have been discerned. And then by employing a space-for-time substitution approach, related environmental factors of soil was analyzed. The analysis results showed that the landscape types and its successional time were the important factors that influenced the spatial distributions of soil characteristic. The detailed results revealed: (1) The *Spartina* marsh succession time was longer, more reduction effect of soil water and salt content, more with the accumulation effect on soil nutrients; (2) The *Suaeda* marsh succession time was longer, more accumulation of soil water and salt content, more with the weakening effect on soil nutrients; (3) The moisture, salinity of soil decreased more and more, soil nutrient increased more and more as the grass marsh existed longer time. This study could help us to evaluate the degradation of wetland and the effect of wetland restoration, as well as to help us to achieve the balance between utilization and reservation.
Keywords: Landscape evolution, coastal wetland, space-for-time substitution, soil properties, Yancheng National Nature Reserve

Introduction

Yancheng National Nature Reserve (YNNR) is one of the most important landscape evolution of China and one of the most complex typical muddy coastal wetlands in the world ecosystem type. The YNNR is one of the world's major winter habitats for red-crowned cranes. It is also a stop-over site for over 300 species of migratory birds from Northeast Asia and Australia (Zhu et al. 2004). So, the habitat of those birds need to be focused, especially the change of its landscape. Currently, studies into the evolution process of coastal wetlands, ecosystem health and reconstruction and ecosystem service values are at the forefront of national wetland research (Sean 2002; Roychoudhury et al. 2003; Zhang et al. 2013). The YNNR has attracted attention from scholars since the 1980s (Zhu and Xu 1982; Zhu et al. 2004) for studies into topography, sedimentation, hydrology, ecology, sustainable development and evolution of landscape (Zhang 1986; Zhang 1991; Shen et al. 2006). The study of landscape evolution which related to ecological process in YNNR is sorely lacked. Although some studies noted the effects of hydrogeomorphologic processes on wetland landscape in coastal area (Gao et al. 2005;

Yao et al. 2009), research results in the relationships between soil processes and the evolution of landscape are very limited.

On the issues of landscape evolution, most of researches focus on identifying the landscape evolution of time and space dynamic using remote sensing methods (Clarkson 1998; Odland 2002; Bender 2005), and landscape evolution is one of the main factors that control the soil properties (Gamboa and Galicia 2011). Vegetaion changes in the landscape can make effective on soil charicteristics and soil charicteristics as a reaction will be on vegetation. Vegetation changes under the forces of nature (not due to human activity) in landscape can be regarded as landscape evolution. Although many studies have focused on the effect of different landscape evolution on the soil properties, the effects of landscape conversion on the soil properties are not fully understood due to the variability of tillage systems and the shortage of historical soil data (Pellegrino et al. 2011). It is generally accepted that the dynamics of landscape is best studied by long-term observations and experiment (Gosz 1996). With regard to soil data shortages, remote sensing, and geographical information system are typically used to identify the changes in landscape and soil properties (El-Shikha et al. 2007), as well as the spatial variability of soil properties in ecosystems (Grunwald et al. 2007). Appropriate space-for-time substitution (SFT) can aid planning of observations and experiments for further study.

The vegetation landscape-soil system, a part of the coastal ecosystem, is a dramatically dynamic and developmental process (Ouyang et al. 2013). The soil develops continuously to reach a balance that relates with vegetation climax along the vegetation landscape succession (Zhang et al. 1990). A quantitative investigation of the soil characteristic evolution and its mechanism in terms of landscape evolution is vital to the study of the development tendency of the coastal system (Li et al. 2013). The core area of YNNR was chosen as the study area to provide a scientific foundation for constructing the eco-environment and rehabilitating the water storing and regulating capacity of the soil. The intact series in the natural landscape evolution on coastal area can be found in this area. The soil characteristics at different landscape evolution stages can be analyzed by SFT in YNNR. Through the collection and analysis of soil samples, the relationship of the process of landscape succession and soil factors can be obtained in YNNR. It provides an in-depth understanding and the basic reference of the coastal wetland ecosystem in the process of succession.

Materials and methods

Study area

The Yancheng coastal marshes are located in the coastal zone of Jiangsu Province, East China (Fig.1). In 1983, YNNR was established to help conserve rare bird species and their habitats. As the marsh area has a rich biodiversity, YNNR was accepted as a member of the UNESCO Man and Biosphere Reserve network in 1993 and was admitted as Northeast Asian Crane Reserve Network Site in 1997 and as an East Asia-Australian Migratory Shorebirds Network Site in 1999. The coast of YNNR is accreting annually with the mudflats moving about 50 to 200 meters seawards per year in the study area (Wang et al. 2006). Its original landscape comprises coastal salt marsh, so the variety of vegetation is poor and dominated by salt tolerant plants. The vegetation landscape had a typical landward succession sere type (Wan et al. 2001): (1) the pioneer species *Spartina alterniflora* dominates the elevated part of the intertidal zone; (2) a *Suaeda salsa* and *Suaeda glauca* community is dominant in the high tidal zone and (3) in the supratidal zone, *Aeluropus littoralis* and *Phragmites australis* are prevalent. The original vegetation landscape of the YNNR was comprised of *Suaeda salsa*, *Phragmites communis Trin* and *Imperata*. In 1963 and 1979, common cordgrass (*Spartina land anglica* C.E. Hubbard) and smooth cordgrass (*Spartina alterniflora Loisel*) were introduced from England and the United States respectively, and after the 1990s, they became the two dominant plants of the intertidal zone in the YNNR (Li et al. 2005).

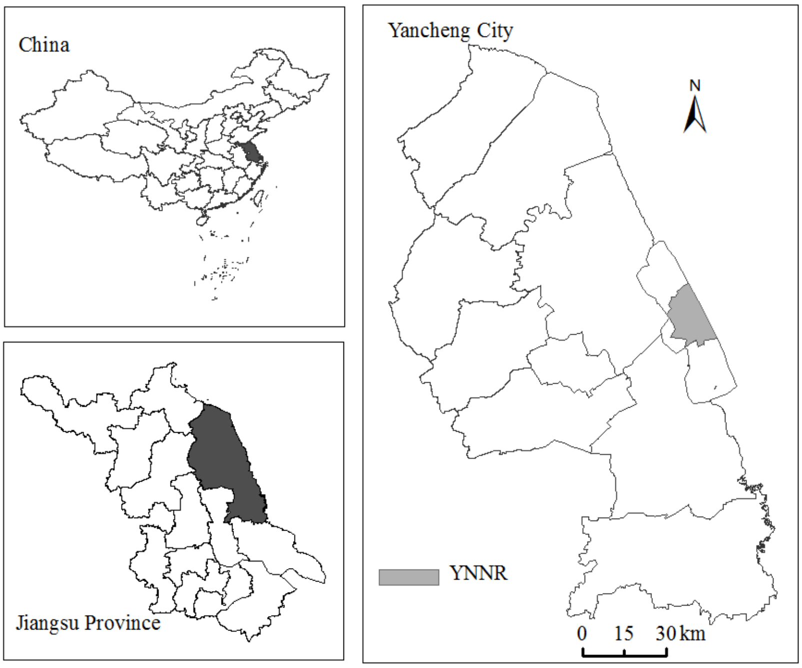

Fig.1 Location of the core area of YNNR

Methods

Reconstruction of landscape history

Landscape types of vegetation were derived from Landsat TM data obtained in June, 1992; May, 2002; and April, 2011, respectively (Table 1). In order to highlight the evolution of vegetation landscape, classification of vegetation landscape was a main concern. A system of landscape classification was established in which landscapes were grouped into 4 categories: the grass land, the *Suaeda* land, the *Spartina* land and the mudflat. The mathods was conducted before in our researches (Wang et al, 2014). All image processing was undertaken using the image analysis software ENVI 4.7. A supervised classification merging the maximum likelihood classify (MLC) and normalized difference vegetation index (NDVI) was used to classify the images with a classification accuracy of above 85% for all classes.

Table 1. Data source for the Thematic Mapper (TM).

Type	TM	TM	TM
Path	119037	119037	119037
Acquisition time	June 11, 1992;	May 20, 2002;	April 23, 2011
Used band	1,2,3,4,5,7	1,2,3,4,5,7	1,2,3,4,5,7

Landscape evolution was a relatively long time span. Under the condition of lack of long-term observation data, we used the “space for time substitution” method to test the impact of time on the relationships between landscape evolution and soil because the landscape evolution over large time scales are beyond the duration of normal observations. This method assumes that important events and processes are independent of space and time (Pickett 1989; Fukami and Wardle 2005). Thus, the landscape configuration in vegetation zones of different ages can represent the evolution of the landscape. Landscape evolution in YNNR was mainly decided by natural factors. Affected by the tidal process, the elevation, soil and hydrology in YNNR was changed by sedimentation with the result of landscape evolution.

Soil sampling

In April 2011, we collected soil samples based on the age of vegetation, with a total of 54 samples being obtained. Each sample consisted of a 500 g mixture of soil from a 0-30 cm profile obtained with the quartering method. All samples were air-dried in the laboratory and then analyzed for soil organic matter (SOM), available phosphorous (AP), available potassium (AK), total nitrogen (TN), total phosphorus (TP) and soil salinity (SS). Soil moisture (SM) was measured in situ using a soil moisture sensor (PICO-BT, made in Germany), and represented in %. SOM, AP, AN, AK, TN and TP are strong indicators of the soil fertility status, while SS indicates the degree of plant desalinization.

Soil nutrient properties were measured in triplicate samples according to spectrophotometric methods. Soil sample was air-dried, ground and screened though 100-mesh sieve before analyzing. SOM was determined using the hydrated heat-photoelectric colorimetry method, with $K_2Cr_2O_7$, H_2SO_4 (analytical pure) and $C_6H_{12}O_6H_2O$ (chemical pure) as chromogenic reagents. Soil AP was measured using the photoelectric colorimetry method, with $NaHCO_3$ and Mo–Sb–VC as the chromogenic reagents. Soil AK was extracted from air-dried soil samples by shaking with 50ml ammonium acetate/acetic acid solution for 30 minutes, and then used the extract flame photometric method. TP was determinate by fusion-colorimetry, and TN was determinated by using the semimicro-Kjeldahl method (Zhai et al., 2006). The extract was filtered and the concentrations was determined with a continuous-flow analyzer (EASYCHEM, made in Italy).The measurement error was within 0.5 mg/kg for all nutrient properties.

Data analysis

Data layers of different vegetation landscape were identified with vegetation age zones in order to test the effects of vegetation landscape age on soil. The age of vegetation landscape can be plotted against time series using remote sensing image.

The soil property data and vegetation landscape data were overlaid to determine the relationship in between based on a plot of the mean±SD. The statistical analysis software SPSS 22 for Windows (Chicago, USA) was applied for the data analysis in this study.

Results

Temporal dynamics of vegetation landscape

From the analysis of the vegetation distribution based on the remote sensing in the three separate years, it was found that the area of spartina land and grass land increased dramatically (from 16 km^2 and 82 km^2 in 1992 to 37 km^2 and 89 km^2 in 2002, and then to 57 km^2 and 98 km^2 in 2011 respectively). *Suaeda* land increased from 54 km^2 in 1992 to 66 km^2 in 2002 and then decreased severely to 32 km^2 in 2011(Fig. 2). The width of vegetation landscape presented the same change trends as vegetation landscape speared ever father seawards. As *Spartina* was introduced into the area between 1960s and 1970s, the landscape and hydrogeomorphologic condition gradually changed because of the function in bank protecting, wave defending and silt promoting.

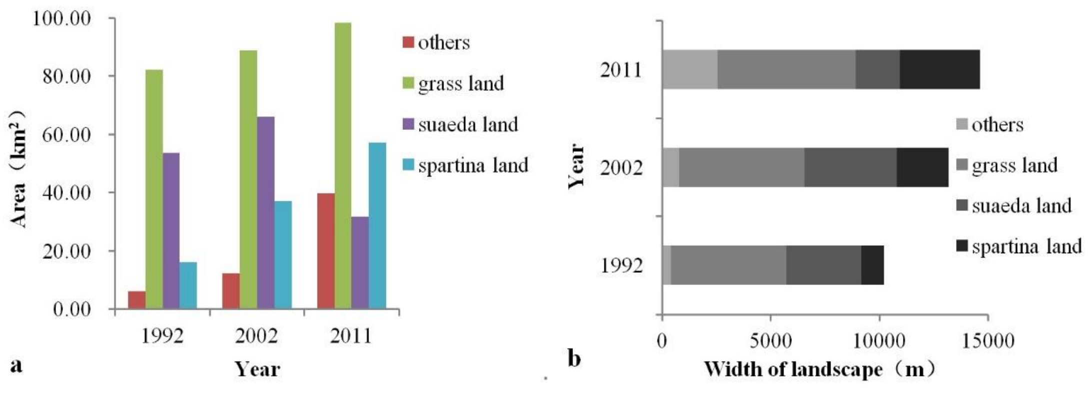

Fig. 2 The area (a) and the width (b) of vegetation landscape types in different years

Distinguish of space for time substitute

Overlaying the maps of vegetation landscape, the characteristics of space for time can be identified by taking 10 years as the time scale. Six samples have belonged to the mudflat for more than 20 years, which can be abbreviated to G>20a. Six samples were located in mudflat from 1992 to 2002 and then substituted by *Spartina* land gradually, which means *Spartina* land in these six samples were less than 10 years (M<10a). In 1992, five samples were covered by muldflat, and then replaced by *Spartina* land, which means *Spartina* land in these five samples were more than 10 years and less than 20 years (10a<M<20a). In the same way, eight samples can be classified to 10a<J<20a, twelve samples can be abbreviated to J>20a, eight samples can be abbreviated to 10a<H<20a, nine samples can be abbreviated to H>20a (Fig. 3).

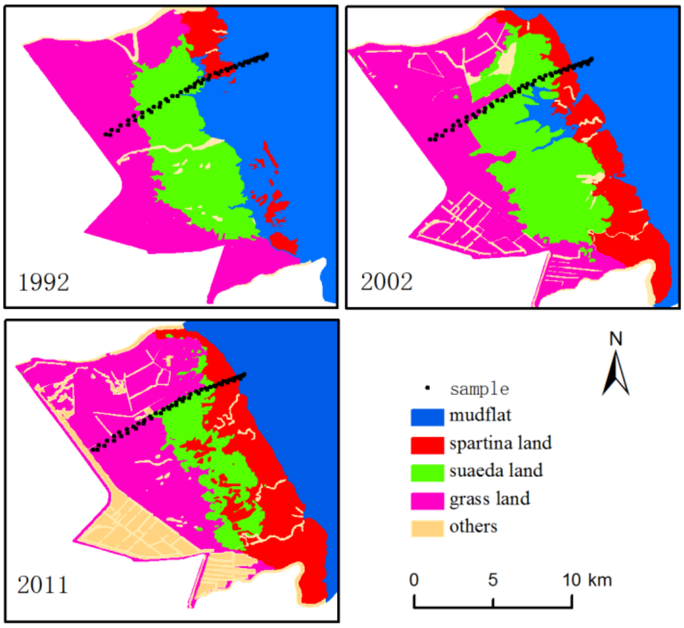

Fig. 3 Soil sampling sites and the change of landscape in YNNR from 1992-2011

Current vegetation landscape and soil characteristic content

With the samples of YNNR obtained during the investigation, the statistical analysis of the soil characteristic contents of the four current landscape types indicated that some of the soil indexes differ among the landscape (Table 2). The amounts of SM and SS were higher in the mudflat soils and lower in the grass and *Suaeda* land soils. The amounts of SOM, TN, TP, AP and AK in *Suaeda* and *Spartina* land were significantly higher than the corresponding amount in mudflat. The standard deviation (SD) of the soil properties in mudflat was higher than those for other landscape.

Table 2. Description of soil characteristics in the current landscape types.

landscape	SM(%)	SS(%)	SOM(%)	TN(mg/kg)	TP(mg/kg)	AP(mg/kg)	AK(mg/kg)
mudflat (G)	55.23±15.27[a]	1.18±0.61[a]	0.38±0.11[a]	93.51±48.96[a]	821.42±320.17[a]	4.58±2.56[a]	97.38±46.20[a]
spartina land (M)	42.99±10.43[a]	1.09±0.58[b]	1.04±0.41[b]	490.28±230.23[b]	830.48±133.16[a]	14.81±9.33[b]	197.85±86.11[b]
suaeda land (J)	44.50±5.21[b]	1.02±0.31[b]	1.06±0.37[b]	406.59±162.41[b]	638.59±66.17[b]	12.49±7.81[b]	169.32±71.10[b]
grass land (H)	37.83±2.15[c]	0.54±0.27[c]	1.00±0.26[b]	310.51±138.11[b]	600.23±63.03[b]	7.74±2.61[ac]	120.49±24.97[a]

[a, b and c] Mean values in columns are significantly different (P<0.05). Values are the mean±SD.

Soil properties during different evolution of landscape

Soil moisture and salinity response

The amounts of SM in the stage of G>20a and M<10a were 55.23% and 52.37%, which are significantly higher than that of other landscape evolution types. The amount of SM in 10a<J<20a and J>20a were the second highest of the analyzed landscape evolution stages, followed by H>10a and then H>20a. The soil salinity contents in M<10a and 10a<H<20a were higher than that in 10a<M<20a and H>20a. The results indicated that the amounts of SM and SS in landscape were affected by the evolution years. According to Table 3, the SD of SM in G>20a and J>20a were higher, with values of 10.27 and 5.58, respectively. The trend of the SM was similar to that of the SS.

Table 3. Description of Soil moisture and salinity in the different landscape evolution stages

Stages	SM(%)			SS(%)		
	mean±SD	min	max	mean±SD	min	max
G>20a	55.23±10.27^{a}	40	90	1.23±0.62^{a}	1.03	1.38
M<10a	52.37±5.52^{a}	45.5	61.9	1.52±0.81^{a}	0.75	2.45
10a<M<20a	33.60±2.69^{b}	30.67	35.97	0.96±0.32^{b}	0.80	1.02
10a<J<20a	43.85±4.72^{b}	36.43	51.96	0.94±0.39^{b}	0.54	1.82
J>20a	45.15±5.58^{b}	39.21	59.49	1.10±0.63^{b}	0.51	2.18
10a<H<20a	38.43±1.56^{c}	36.87	40	0.64±0.32^{b}	0.43	1.01
H>20a	37.23±2.31^{c}	34.36	41.29	0.44±0.26^{b}	0.14	.87

$^{a,\ b\text{ and }c}$ mean values in columns are significantly different (P<0.05). Values are the mean±SD. The landscape of mudflat, spartina land, suaeda land and grass land can be abbreviated to G, M, J and H.

Soil organic matter, total nitrogen and total phosphorus response

The soil organic matter (SOM) content in the various landscape evolution stages ranged from 0.26% (G>20a) to 1.17% (10a<M<20a). The total nitrogen (TN) content in 10a<J<20a was significantly higher than the amounts in other stages, and the amounts of the total phosphorus (TP) in M<10a and 10a<M<20a were high, while that in G>20a was the smallest among all the analyzed stages (Table 4).

Table 4. Description of SOM, TN and TP in the different landscape evolution stages

	SOM(%)			TN(mg/kg)			TP(mg/kg)		
	mean±SD	min	max	mean±SD	min	max	mean±SD	min	max
G>20a	0.26±0.12^{a}	0.16	0.48	162.74±28.98^{a}	80.20	195.22	553.53±229.17a	221.00	753.79
M<10a	0.91±0.50^{b}	0.33	1.74	476.03±204.25^{b}	115.25	832.68	862.75±122.52b	713.29	935.48
10a<M<20a	1.17±0.11^{b}	1.06	1.27	504.54±250.18^{b}	355.39	793.37	798.21±171.00b	678.37	994.03
10a<J<20a	1.11±0.35^{b}	0.70	1.79	526.94±166.41^{b}	363.27	745.31	659.58±91.33a	477.89	816.20
J>20a	0.95±0.39^{b}	0.00	1.70	286.23±65.03c	204.14	454.07	617.60±41.47a	496.69	678.37
10a<H<20a	0.98±0.27^{b}	0.70	1.25	274.26±59.83c	224.21	340.52	580.22±106.06a	459.10	656.44
H>20a	1.01±0.27^{b}	0.56	1.58	346.77±149.52c	219.91	684.39	620.25±46.91a	521.75	687.77

$^{a,\ b\text{ and }c}$ mean values in columns are significantly different (P<0.05). Values are the mean±SD. The landscape of mudflat, spartina land, suaeda land and grass land can be abbreviated to G, M, J and H.

Available phosphorous and available potassium response

The 10a<J<20a soil had the highest AP content among all evolution stages. The M<10a and10a<M<20a have significantly higher AK content than the 10a<J<20a, as well as all the other landscape evolution stages. The landscape evolution can cause the AP content in the *Suaeda* land to decrease dramatically. Except for the SD of 10.01 for the AP in the10a<J<20a soil, the SD of the AP in the other landscape evolution stages were relatively small (1.25-6.65). However, the SD of the AK content ranged from 17.24 to 96.87, and the mean values of the AK content ranged from 67.81 to 198.43 mg/kg (Table 5).

Table 5. Description of AP and AK in the different landscape evolution stages.

	AP(mg/kg)			AK(mg/kg)		
	mean±SD	min	max	mean±SD	min	max
G>20a	3.13±1.56a	1.01	5.96	67.81±30.20a	42.02	100.84
M<10a	13.62±6.75b	5.11	35.71	198.43±96.87b	101.00	340.30
10a<M<20a	12.22±1.25b	10.84	13.28	197.27±78.75b	117.62	275.08
10a<J<20a	19.69±10.01b	9.52	33.68	175.78±64.64b	128.28	340.30
J>20a	9.97±2.24b	5.96	13.46	162.86±76.50b	92.51	340.30
10a<H<20a	8.80±2.50ab	6.05	10.93	118.67±17.24ab	102.71	136.95
H>20a	6.68±2.55ab	4.36	12.53	122.30±27.91ab	84.38	170.47

$^{a,\ b\text{ and }c}$ mean values in columns are significantly different (P<0.05). Values are the mean±SD. The landscape of mudflat, spartina land, suaeda land and grass land can be abbreviated to G, M, J and H.

Soil physicochemical indices and vegetation characteristics

The data of plant height, average coverage, ground biomass and underground biomass were collected in the same place of soil samples. Compared to other vegetation communities, plant height, the ground and underground biomass of *Spartina* land were higher (Table 6). The average vegetation height of *Spartina* marsh, *Suaeda* marsh, and grass marsh were 1.50 m, 0.35 m and 0.70 m, respectively. Their average coverage was 87.5, 62.5 and 92.5%, respectively. The aboveground biomass of *Spartina* marsh was 1.14 kg/m2, which was the highest value. The underground biomass of *Spartina* marsh was the highest value similarly.

Table 6. Characteristics of vegetation under different landscapes.

	plant height（cm）	average coverage（%）	ground biomass（kg/m^2）	underground biomass（kg/m^2）
G	0	0	0	0
M	155	87.5	1.14	0.955
J	35	62.5	0.135	0.08
H	69.5	92.5	0.44	0.565

The relationship between the characteristic of plants and soil factors was shown in Table 7. Vegetation coverage had a significant positive correlation between soil organic matters. The correlation coefficient was 0.907. It also had a significant positive correlation between biomass and soil total nitrogen, including aboveground and underground biomass, which reflected the kind of interdependent relationship between vegetation characteristics and soil properties.

Table 7. Relationship between soil and vegetation characteristics.

	SM	SS	SOM	TN	TP	AP	AK
plant height	-0.520	-0.195	0.566	0.694	0.384	0.656	0.877^{*}
average coverage	-0.861^{*}	-0.624	0.907^{**}	0.653	-0.437	0.459	0.417
ground biomass	-0.568	-0.294	0.506	0.907^{**}	0.391	0.587	0.893^{*}
underground biomass	-0.479	-0.224	0.451	0.875^{*}	0.385	0.480	0.806^{*}

** means significantly different ($P<0.01$), * means significantly different ($P<0.05$)

Discussions

We used the space for time substitution method to investigate the effects of time on landscape changes and found that grass land and *Spartina* land in the YNNR did show a generally increasing trend with time. Since the 2002, the reduction of *Suaeda* land has accelerated. The time of landscape evolution for one type can play an important role in the soil indicators. The longer time *Spartina* land settled, the lower content moisture, salinity of soil contained, the higher content of the soil nutrient contained, but the condition was just the reverse of *Suaeda* land. These findings are consistent with the temporal evolution trend observed for some soil properties (Li et al. 2007; Sun et al. 2011) and for biodiversity (Shen et al. 2006; Sun et al. 2012).

Soil properties improved as landscape evolved from mudflats to vegetation, as indicated by soil fertility such as organic matter, total nitrogen, and total phosphorus, available phosphorous and available potassium. An earlier study of the YNNR also found that moisture and salinity concentration levels decreased after vegetation settled and evolved (Yao et al. 2009). Soil properties differed significantly among evolution types. The variation of TN in the 10a<J<20a zone was much higher than in J>20a types. This could have occurred because the soil in J>20a zone of our study area is rather old when compared to 10a<J<20a and the soil nutrition easily lost with lower biomass of *Suaeda* land. Nutrient levels in the soil of *Spartina* land (10a<M<20a and M<10a) were high when compared to that in the *Suaeda* land, which is consistent with a study of *Spartina* in YNNR that revealed that higher biomass can improve and maintain soil fertility (Ren et al. 2011). Because of none disturbing of any human activity, sampling sites was restricted along the unique road towards sea. The landscape is under the rule of belt shaped distribution along the coastline. The soil properties in the former studies (170-460mg/kg for TN, Mao et al. 2009; 550-850mg/kg for TP, Zhong et al. 2010) seems to have similar level than the soil in our study area (162-562mg/kg for soil TN, and 553-862mg/kg for TP, Table 4). However, when compared to the TN in surface sediments of agriculture nearby study area (830mg/kg) (Mao et al. 2010), and the concentration of soil organic matter in our study area was much lower.

Landscape of vegetation evolution depends on soil as the important environmental conditions. On the contrary, the characteristics of the vegetation community inevitably affect soil properties. The soil in one stage not only reflects the result of interaction between vegetation community and the soil before, at the same time also determines soil foundation and the initial state of subsequent vegetation community (Pang et al. 2004). Coastal wetland vegetation characteristics have important influence on the tidal flat soil. The vegetation coverage, distribution area, especially plant biomass can change the soil properties (such as nutrient content) (Mao et al. 2010). Due to the differences of vegetation coverage, biomass, plant height, root length, the accumulated rate of soil nutrient in sediments are vary (Ren et al. 2011).

The growth of *Spartina* grass plays a controlling role in tidal flat sedimentation with the advantage to the nutrient storage (Mayer et al. 1988). There were the highest height, the highest coverage and the highest biomass of *Spartina* land. It had a significant positive correlation between biomass and soil total nitrogen.

Although the results from this study were obtained from two sampling strips, the trend of change in landscape with time and variation of soil properties under different evolution stages can be used as a reference for other part of YNNR. Therefore, the results presented herein will provide scientific support for future management. The results about effects of time and landscape evolution on the soil also contribute to the overall understanding of the relationship between landscape patterns and processes.

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