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Succession in soil and vegetation caused by coastal embankment in southern Laizhou Bay, China—Flourish or degradation?

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ABSTRACT

Coastal wetland degradation and loss caused by intensive human activities, such as land reclamation and embankment, is a serious environmental problem. In this paper, we studied the succession of soil and vegetation in a coastal wetland dominated by Chinese tamarisk (*Tamarix chinensis*) community after the construction of a seawall. When the intertidal wetland became supratidal wetland, soil salinity firstly decreased and the gradient from sea to land became weaker. Next, the area of vegetation and plant species diversity increased, and the phenomenon of plant zonation disappeared. We reasoned that the rooted cause of soil and vegetation succession was the change in hydrological environment. Moreover, a Drivers-Pressures-State-Impacts-Response (DPSIR) model was used to analyze the relationship between human activities and coastal wetland. Using this model, we presented the potential problems that might arise in this wetland and predicted that vegetation flourishing was only a short term phenomenon but wetland degradation was the final consequences due to excessive exploitation of groundwater. At last, we proposed a few of operable measures as responses to these potential problems from the perspective of coastal management.

1. Introduction

Wetlands are an essential component of the natural environment to maintain the balance in hydrological systems and their associated habitats (UNESCO, 1994; Barbier et al., 1997). They are considered as one of the most productive ecosystems on earth (Gibbs, 2000; Mitsch and Gosselink, 2007), and provide many environmental benefits to human communities, such as water purification, flood control etc. (Barbier et al., 1997). However, many wetlands in the world were threatened by the global climate changes and human activities, which directly decreased the biodiversity and ecosystem services (Valiela and Fox, 2008). On the one hand, people make great efforts to preserve natural wetlands (Gibbs, 2000; Valiela and Fox, 2008). On the other hand, they also build constructed wetlands for the purpose of wastewater treatment and biodiversity conservation (Vymazal, 2008).

The coastal zone represents the interface between the land, ocean and atmosphere; therefore, coasts are sensitive to natural and man-made changes (Klein and Nicholls, 1999). Due to coastal vulnerability, coastal wetlands disappear at higher rate than inland wetlands (Valiela and Fox, 2008). In China, coastal wetlands also face the fate of degradation and loss (Lu et al., 2000; Lin et al., 2007). Rapid economic growth and population expansion have been recognized as the major driving forces of coastal wetland loss (Wu et al., 2012). Facing the problem of imbalance between land supply and demand, land reclamation from sea was usually treated as the most direct approach to create new land (Bi et al., 2012; Wu et al., 2012). Until 2000, half of China's coastal wetlands have been lost due to reclamation and coastal engineering (Burchett et al., 1998; Gu et al., 2003).

As one of the three largest Bays of the Bohai Sea, there are diverse wetlands in Laizhou Bay (Fig. 1). In the southern coast of Laizhou Bay, inter-tidal marshes and mudflats are two typical coastal wetlands (Lu et al., 2000). Salt production by evaporating seawater has more than 2 500 years of history in this region, and salt industry always played an important role in local economic development. Now, Laizhou Bay is still one of the major origins of the crude salt in China. During the past three decades, about 49.1% of the natural wetlands have been reclaimed and used as salt pans in southern Laizhou Bay (Zhang et al., 2009). In recent years, local people pump saline groundwater to produce salt instead of seawater. To protect their brine wells on the mudflats, seawalls were built. As the seawater was blocked, inter-tidal wetlands became supratidal wetland. Understanding the change of coastal

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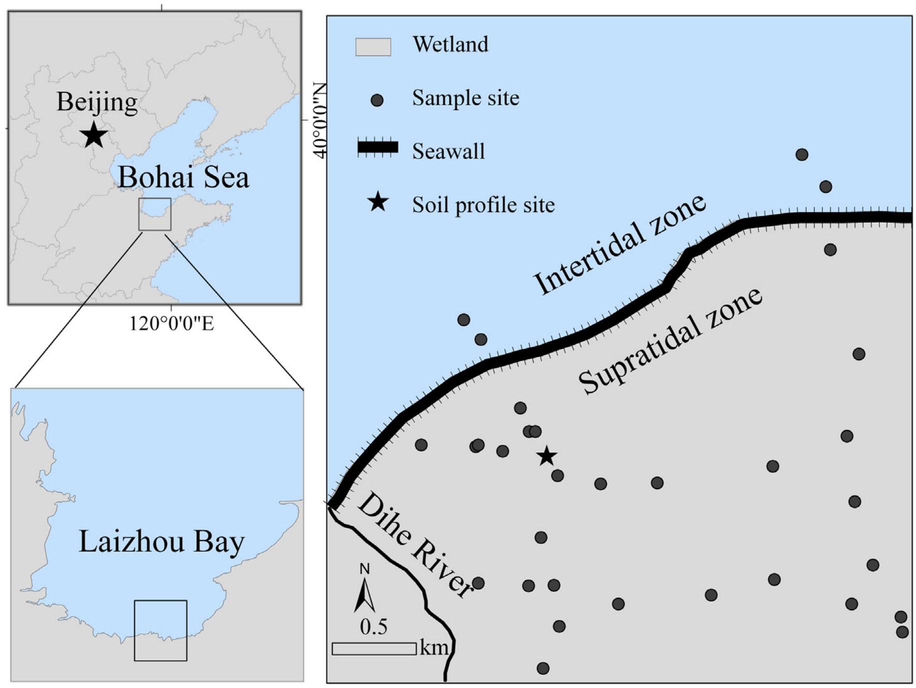

Fig. 1. Location of the study area and the spatial distribution of all sample sites.

wetland subject to those seawalls is critical to the management and protection of coastal wetlands.

In previous studies, ecologists usually paid attention on the change of wetlands from the perspective of land use change or landscape succession (Zhang et al., 2004, 2006, 2009; Wu et al., 2009). However, the succession of soil and plant community after the construction of seawalls in this area was not studied. In this paper, the succession of soil and plant community and their spatial relationships were firstly studied. Meanwhile, the future succession and management of coastal wetland within the framework of Drivers-Pressures-State-Impacts-Response (DPSIR) model was also discussed.

2. Materials and methods

2.1. Study area

The study area is located in southern coast of Laizhou Bay within the Changyi National Marine Specific Protection Area (CNMSPA, 37°07′N, 119°36′E) in Shandong province, China (Administration of CNMSPA, 2010). The local climate is continental monsoon climate of calefactive temperature. Summers are moist and hot while winters are dry and cold. Average temperatures are −3.8 °C in January and 25.9 °C in July. The annual average precipitation is 628 mm but the annual average evaporation is 1776 mm. The coast is a wide plain with a very small slope, and the width of the intertidal zone is about 3–5 km. The layout declines from south to north and the average slope is 0.2‰. The study area is below the sea level and the average elevation is about −1 m.

There is about 3 000 ha coastal wetland in this area. Before the seawall was constructed, the study area was intertidal zone. However, the wetland was not totally submerged by seawater except astronomical tide or storm tide occurred. On the west side of the study area, there is a seasonal river named Dihe (Fig. 1). In rainy season, the wetland is also affected by the flood. The seawall was constructed in 2000 and repaired yearly in the following ten years. It was built with soil and covered by an impermeable cloth, then both seawater and river water was blocked (Fig. 2C). The seawall became the new artificial coastline and its length was about 5 km. A few hundreds brine wells are located in the supratidal wetlands.

The soil in the wetland is a mixture of sand, clay and fragmented seashells. The vegetation is dominated by shrubs with grasses. As Chinese tamarisk (*T. chinensis*) is the dominant species in the shrub, it is also named as northern tamarisk shrub wetland as famous as the mangroves wetland in southern China (Weifang Station of Marine Environment Monitoring, SOA, 2007). In 2007, CNMSPA was formally approved by State Ocean Administration of China. The protected area covered most supratidal wetlands in this area and was recognized as the largest natural tamarisk shrub in northern China (Administration of CNMSPA, 2010). The protected area was also the habitat of many rare animal species such as *Otis tarda*, *Grus eucogeranus*. As the brine wells and channels were not located in the core zone of the protected area, they were not abandoned and demolished yet (Fig. 2D).

2.2. Data collection

2.2.1. Remote sensing data

In order to detect the dynamics of wetlands in this region, a series of Landsat TM images in growing seasons of 2000, 2006 and 2009 were selected to quantify the wetland distribution. Supervised classification method was then used to estimate the areas of vegetation at the three stages by ERDAS IMAGINE 9.2. The supervised classification is the procedure most often used for quantitative analysis of remote sensing image data. It rests upon using a variety of algorithms to label the pixels in an image as representing particular ground cover types, or classes (e.g. Richards and Jia, 2006). The classification results were tested by the following wetland plant survey.

2.2.2. Field sampling and lab analysis

Four transects were established in 2012, parallel and vertical to the coastline, respectively, to detect the gradient of plants and soil changes with the distance to seawall (Fig. 1). Transects were

Fig. 2. Different vegetation landscapes on the two sides of the seawall. A: intertidal wetland with two species *S. salsa* and *Tamarix chinensis*. B: supratidal wetland with *Tamarix chinensi* dominated plant community; C: seawall covered by an impermeable cloth; D: the channels in the supratidal wetland.

designed using a global positioning system (GPS). There were 35 sampling points in total, among them four sampling points were located in intertidal zone and others were located in supratidal zone. To test the variation in soil properties affected by the seawall at a long-term scale, we also conducted a soil profile with the depth of 180 cm in the supratidal zone. All sampling points were placed 30 m far away from brine wells, roads and water channels, in order to avoid the disturbance of other human activities (Fig. 1).

Soil cores were collected at each sampling point (5 cm, 20 cm and 50 cm in depth, respectively). The soil samples were then sent to indoor lab to analyze their properties, including pH, salt content (SC, %), available K (K, ppm), available P (P, ppm), available N (N, ppm) and soil organic matter (SOM, %), using standard methods (Zhang, 2006). For this 180 cm profiles, soil cores were also collected for each 20 cm depth, e.g. 0 cm, 20 cm, 40 cm, *etc*., to analyze the percentage of total salt and soil particle size (Zhang, 2006).

For each soil sampling point, a 10 × 10 m quadrat was used for woody investigation and three 1 × 1 m plots were selected randomly in the 100m^{2}quadrat for grass investigation. As mentioned above, *T. chinensis* was the only woody plant (shrub), then all *T. chinensis* were measured for number, height and canopy diameter in N–S and E–W directions, respectively. All grasses were measured for species and their percentage covers in these 1 × 1 m plots.

2.2.3. *Statistical analysis*

One-way ANOVA was used to compare the significance of differences of soil and plant variables between intertidal zone and supratidal zone by the software SPSS 13.0. In field investigation, problems caused by spatial heterogeneity must be carefully considered. The phenomenon of spatial autocorrelation, i.e., the spatial dependence of the values of a variable, is common in field investigation. Therefore, Mantel test was then used to test spatial autocorrelation of soil variables and plant variables in *T. chinensis* communities and their spatial cross-correlations using the software PASSaGe 2.0 (Rosenberg and Anderson, 2011).

Mantel test is a permutation test that takes into account the spatial and or temporal autocorrelation among observations by assessing the correlation between distance matrices. A partial Mantel test assesses the partial correlation between two matrices while keeping the effects of a third matrix constant (Mantel, 1967; Fortin and Gurevitch, 1993). We used the spatial correlation to explain the potential influences of seawall on *T. chinensis* communities and soil properties.

In this paper, three kinds of distance matrix were used: a variable distance matrix containing the absolute values of the difference between soil properties (or plant variables) at pairs of locations, a spatial distance matrix containing the Euclidean distances between pairs of locations, and a design distance matrix for testing the effects of distance to seawall to test their influences. For each test, one thousand permutations were conducted and the level of significance 0.05 was used to assess the significance of a relationship between two matrices (Fortin and Gurevitch, 1993).

3. Results

3.1. *Plant community*

The area of wetland vegetation was 16.98, 17.89 and 18.61 km^2, in 2000, 2006, and 2009, respectively, with an obviously increasing trend after the construction of the seawall. In the intertidal wetlands, there are two plant species: *Suaeda salsa* and *T. chinensis*. However, there are 13 plant species in total and 12 of them are grasses in the supratidal zone. In seawall-influenced region (supratidal zone), the mean density of *T. chinensis* was about 0.16/m^2, with the mean height of 1.64 m and the mean crown diameter of 1.56 m. The mean species diversity in *T. chinensis* community was 0.3/m^2. *Suaeda glauca*, *Phragmites australis* and *Setaira viridis* were the three common species.

Height of *T. chinensis* has extremely significant autocorrelation ($p = 0.001$) and is significantly related to mean canopy diameter ($p = 0.001$) in the seawall-influenced area. The species diversity has also significant autocorrelation ($p = 0.04$) and is significantly

Table 1
Mantel test results for spatial correlation of plant variables in *Tamarix chinensis* community.

	A		C		H		S	
	Mantel's r	*p*	Mantel's r	*p*	Mantel's r	*p*	Mantel's r	*p*
A	0.008	0.223	0.149	0.070	0.134	0.103	0.045	0.619
C			0.145	0.060	0.835	**0.001**	0.201	**0.002**
H					0.204	**0.001**	0.835	**0.001**
S							0.357	**0.040**

Note: A, Abundance; C, canopy diameter; H, Height, and S, species diversity. The same as following. The *p*-values in bold (<0.05) indicate insignificance in statistical test.

related to height ($p = 0.001$) and mean canopy diameter ($p = 0.002$) (Table 1).

3.2. Soil properties

Results of ANOVA analysis showed that there were extremely significant differences in pH and SC between intertidal zone and supratidal zone (both *p*-values equal to 0.0000). However, there was no difference in K, P, N and SOM. The construction of seawall has mainly influenced the distribution of salt content from sea to land, but not the distribution of nutrient elements. The results have also indicated that K, P and SOM were significantly different among the three soil layers (all *p*-values <0.001), but pH, SC and N were insignificantly different (Table 2), which indicated that nutrient elements have different patterns at vertical scales in soil.

Mantel test results showed that the soil properties in seawall-influenced area had significant autocorrelation. Especially, pH and SC in three layers had significant patterns (all *p*-values < 0.05). In addition, P in the 5 cm layer ($p = 0.03$)) and K in 20 cm layer ($p = 0.02$) have significant autocorrelation. However, the spatial autocorrelation in pH and SC have been weakened when considering the influences of distance to seawall (all *p*-values > 0.05). There was no obvious spatial influence of distance to seawall on K, P, N and SOM, too (Table 3). The decreasing gradient of salt content from sea to land has been greatly influenced by the seawall.

Analysis of soil profile showed a pattern of horizons that was directly related to the soil salinity. In vertical direction, total salt increased from 0 to 0.7 m in depth. We speculated that the increasing trend was caused by rainwater leaching. At the depth of 0.6 m, there was a 10 m clay layer and the average soil particle size was about 7–10 μm. Therefore, it formed a water-resisting layer and the salinity was very high there. At the depth of 1.6 m, there was a 20 cm layer consisting of many fragmented seashells and the average particle size reached 100 μm. As the mineralization of seashells, the total salt was also larger than average. The pattern of horizons was probably the result of deposition but out of the scope of this paper.

3.3. Soil–plant relationship

Mantel test results showed that both the mean height of *T. chinensis* and species diversity was significantly correlated to pH in soil (*p*-values < 0.05). However, abundance of *T. chinensis* and their canopy diameter had no significant spatial relationship with pH (*p*-values > 0.05). Similarly, the results also showed significantly spatial relationships between the mean height of *T. chinensis* and species diversity in this community with SC (Table 4). However, there were insignificant relations between the two vegetation variables with N, K, P and SOM in soil.

Table 3
Mantel test results for spatial correlation between soil properties in different layers.

	I-layer		II-layer		III-layer	
	Mantel's r	*p*	Mantel's r	*p*	Mantel's r	*p*
pH	0.200	**0.040**	0.009	**0.007**	0.346	**0.002**
SC	0.307	**0.002**	0.439	**0.001**	0.399	**0.001**
K	−0.050	0.650	0.220	**0.030**	0.090	0.130
P	0.220	**0.020**	−0.110	0.895	−0.003	0.490
N	−0.050	0.590	−0.042	0.580	0.121	0.080
SOM	0.030	0.320	0.106	0.145	−0.097	0.790
PH/D	−0.104	0.760	0.040	0.330	0.053	0.200
SC/D	0.016	0.290	0.126	0.080	0.209	0.070
K/D	−0.195	0.950	−0.086	0.750	0.077	0.213
P/D	0.350	0.060	−0.129	0.896	−0.130	0.930
N/D	−0.019	0.260	−0.017	0.350	0.134	0.080
SOM/D	0.090	0.180	0.240	0.051	−0.054	0.569

Note: D, distance to seawall. The *p*-values in bold (<0.05) indicate insignificance in statistical test (the same in Table 4).

Table 4
Mantel test results for spatial correlation between vegetation and soil properties.

	Mantel's r	*p*		Mantel's r	*p*
A/pH	0.014	0.16	A/SC	0.0018	0.212
C/pH	0.158	0.07	C/SC	0.149	0.07
H/pH	0.22	**0.005**	H/SC	0.217	**0.004**
S/pH	0.36	**0.02**	S/SC	0.08	**0.009**

4. Discussion

For wetlands, change in hydrological environment was considered as the rooted reason of soil and vegetation succession (Ma et al., 2012). Hydrological environment change in coastal wetlands usually starts with hydraulic alteration (Crooks et al., 2011). In this study, the hydraulic alteration was specifically referred to the embankment in the intertidal wetland. Before the seawall was constructed, the soil salinity was mainly influenced by the seawater. The soil salinity was almost equal to that of seawater. Only two plant species *S. salsa* and *T. chinensis* that are tolerant to salt can survive in the intertidal wetland. After coastal embankment, seawater was blocked and the freshwater became the determinant factor in the supratidal wetlands. Salts were leached by rainwater towards the deepest soil layers and the salinity of surface soil decreased. Salinity analysis of the soil profile verified this viewpoint (Fig. 3). It seems that the supratidal wetland is nearly out of the influence of seawater currently. Also, results from

Table 2
Mean and S.D. of soil properties of three soil layers in intertidal zone and supratidal zone.

Layer	Intertidal zone			Supratidal zone		
	I	II	III	I	II	III
pH	8.270 (0.383)	8.010 (0.110)	8.095 (0.026)	8.393 (0.421)	8.617 (0.377)	8.826 (0.392)
SC	0.320 (0.292)	0.679 (0.285)	0.721 (0.336)	0.056 (0.017)	0.099 (0.100)	0.116 (0.122)
K	1 581.250 (125.834)	1 665.250 (12.285)	1 495.500 (212.572)	1 625.059 (157.263)	1 664.000 (8.374)	1 515.882 (154.931)
P	8.015 (5.451)	7.443 (2.193)	18.893 (4.721)	14.414 (6.566)	11.046 (3.055)	20.071 (7.083)
N	4.848 (1.250)	2.888 (2.655)	1.365 (0.967)	9.837 (14.363)	9.001 (14.707)	1.886 (0.648)
SOM	1.202 (0.539)	1.058 (0.220)	0.817 (0.104)	1.112 (0.382)	0.812 (0.239)	0.712 (0.231)

Note: SC, salt content (%); K, available K (ppm); P, available P (ppm); N, available N (ppm) and SOM, soil organic matter (%). The same as following.

spatial analysis indicated that soil salinity was not spatially correlated to the distance to seawall (Table 3). Contrary to salt, changes in soil nutrients (e.g. K, N, P and SOM) were not obvious because of the influences of plants on the surface soil. Although the spatial pattern of soil moisture was not included in this paper, it was reported in previous references that the moisture of surface soil was not spatially related to distance to seawater (Tang et al., 2011).

When the soil properties changed, the succession of plant communities followed. When the soil salinity decreased to 0.1%, *Artemisia capillaris*, *S. viridis*, *S. glauca* and other plant species that can survive in moderate salty soil successfully invaded (Tang et al., 2011). During this process, the vegetation increased and the community structure changed. Remote sensing images indicated that the newly grown vegetation was mainly located near the seawall on the land side. The height of dominant species – *T. chinensis* and the species diversity in this community have also shown strongly spatial pattern and closely related to soil salinity at current condition (Tables 1and 4). In northern China, without influences of human activities, wetland zonation changes gradually from subtidal aquatic beds, mudflats, salt marsh, intertidal shrubs and finally to supratidal shrubs (Han et al., 2006). In particular, the gradient of plant community from intertidal shrubs to supratidal shrubs is very obvious (Zhang et al., 2004). In this study, we found that the gradient of vegetation disappeared within the supratidal wetlands caused by coastal embankment.

Until now, we have understood the impact of coastal embankment on soil and plant succession. However, the impact of other human activities, such as salt production and groundwater abstraction, which might also alter the local hydrological environment, were not well recognized. As excessive groundwater abstraction, the depth of water table increased to 30 m in the past ten years (Administration of CNMSPA, 2010). Moreover, as the freshwater from the Dihe river was also blocked, then, precipitation became the only freshwater supply for the wetland. Rainwater filter to deeper soil layer until meets the underground brine water resulting in another problem-wetland drying (Administration of CNMSPA, 2010). It was also reported that the trend of precipitation in this area was decreasing in the past three decades (Gao and Hou, 2012). So, we speculate that the succession of plant community will continue and only species, which are tolerant to dry environment, can survive. In other word, the flourishing of vegetation cannot last for a long time if the pressures from human activities continue and increase. In that case, the long term trend of vegetation succession is degradation.

We use a Drivers-Pressures-State-Impacts-Response (DPSIR) model to analyze the mutual relationship between human activities and environment and to propose some operable measures to solve the potential problems. DPSIR is an extension of the famous pressure-state-response model developed by the Organization for Economic Co-operation and Development (OECD, 1993) and has been adopted by European Environmental Agency (EEA, 1999) to relate human activities to the state of the environment. It also provides a logical framework for evaluating changes in coastal wetlands and their impacts (Lin et al., 2007). It also works well in fisheries management (Mangi et al., 2007; Martins et al., 2012) and interactions between the socio-economic system and the ecosystem (Marques et al., 2009; Pinto et al., 2013). The framework of DPSIR model of the study area is shown in Fig. 4. Salt production and industry is the major anthropogenic driving force. To exploit brine water, people drilled brine wells and constructed seawall to protect brine wells and channels. These pressures lead to hydraulic alteration and aquifer drawdown. Intertidal wetlands become supratidal wetlands. In this paper, the fact that embankment-induced hydrological environment change resulted in soil and plant community succession was clear. Although the causal relationship between underground brine water abstraction and wetland drying is not evident, we still treat it as possible pressure.

As responses, we also propose the following measures. First, grazing and hunting should be strictly prohibited for the purpose of biodiversity conservation in the coastal ecosystem (Administration of CNMSPA, 2010). Moreover, as the dominant and only woody species, *T. chinensis* is crucial to the wetland ecosystem. Artificial regeneration is encouraged where the vegetation is damaged (Zhang et al., 2004). Second, the problem of wetland drying can probably be solved by water diversion. As the wetland is near the Dihe river, it is easily to draw freshwater from the river. Moreover, we can construct ecological ponds to reserve water. The method, which was usually adopted in constructed wetlands, could also bring other benefits such as nutrients inflow and water purification. Third, we recommend highly a synthetic environmental assessment of brine water exploitation. If the assessment verifies that brine water exploitation seriously impacts the ecological health, we also suggest demolishing the brine wells and channels. Otherwise, we can restructure the business of local residents. Local government planned to construct a wetland park and tourism might replace the traditional salt industry (Administration of CNMSPA, 2010). Seeking a balance between economic development and environment protection will be a challenge for wetland managers in a long period.

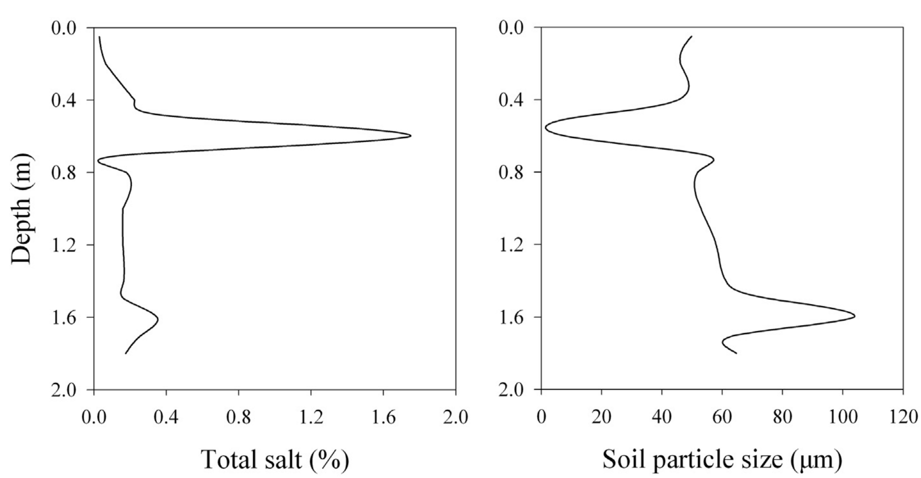

Fig. 3. Changes in total salt and soil particle size of soil profile. At the depth of 0.6 and 1.6 m, there were clay layer and sand layer with fragmented seashells, respectively.

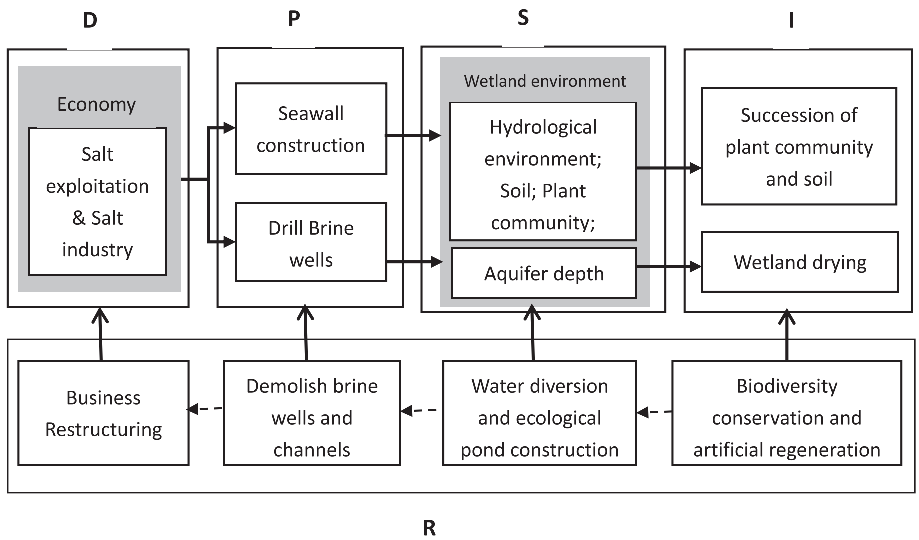

Fig. 4. Drivers-Pressures-State-Impacts-Response (DPSIR) model of coastal wetland in southern coast of Laizhou Bay.

5. Conclusions

In this paper, we studied the succession of soil and plant in a supratidal wetland enclosed by a seawall. After the construction of seawall, the temporal trend of vegetation and biodiversity was increasing. From spatial perspective, the gradient patterns of wetland plants and soil properties have been changed greatly, which formed a clear boundary between intertidal and supratidal zones. There were extremely significant differences in pH and soil salinity between intertidal zone and supratidal zone. Plant–soil relationship in the impacted region has also changed. The mean height of *T. chinensis* and species diversity have significantly related to pH and soil salinity in soil. We concluded that the current flourish of vegetation was the result of embankment. However, the potential impact of underground brine water exploitation is pessimistic. We recommend the effective management and engineering measures to response the adverse impact brought by intensive human activities.

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References

Administration of CNMSPA, 2010. Implementation Strategy of Ecosystem Restoration of Changyi National Marine Specific Protection Area (in Chinese).
Barbier, E.B., Acreman, M., Knowler, D., 1997. Economic Valuation of Wetlands, a Guide for Policy Makers and Planners. Ramsar Convention Bureau, Gland, Switzerland.
Bi, X., Liu, F., Pan, X., 2012. Coastal projects in China: from reclamation to restoration. Environ. Sci. Technol. 46, 4691–4692.
Burchett, M.D., Allen, C., Pulkownik, A., Macfarlane, G., 1998. Rehabilitation of saline wetland, olympics 2000 site, Sydney (Australia)-II: salt-marsh transplantation trials and application. Mar. Pollut. Bull. 37, 526–534.
Crooks, S., Herr, D., Tamelander, J., Laffoley, D., Vandever, J., 2011. Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems. Environment Department Paper 121. World Bank, Washington, DC.
EEA, 1999. Environmental Indicators: Typology and Overview. Technical report No 25.
Fortin, M., Gurevitch, J., 1993. Mantel tests: spatial structure in field experiments. In: Scheiner, S.M., Gurevitch, J. (Eds.), Design and Analysis of Ecological Experiments. Chapmen and Hall, New York, NY, USA, pp. 342–359.
Gao, M., Hou, X., 2012. Trends and multifractal analyses of precipitation data from Shandong Peninsula, China. Am. J. Environ. Sci. 8 (3), 271–279.
Gibbs, J.P., 2000. Wetland loss and biodiversity. Conserv. Biol. 14 (1), 314–317.
Gu, D., Zhao, X., Xia, D., 2003. Systemic analysis of the environmental pressure factors to the degradation of coastal wetlands in China. Acta Oceanol. Sinica 25, 78–85.
Han, Q., Huang, X., Shi, P., Zhang, Q., 2006. Coastal wetland in south China: degradation trends, causes and protection countermeasures. Chin. Sci. Bull. 1, 121–128.
Klein, R.J.T., Nicholls, R.J., 1999. Assessment of coastal vulnerability to climate change. Ambio 28 (2), 182–187.
Lin, T., Xue, X., Lu, C., 2007. Analysis of coastal wetland changes using the "DPSIR" model: a case study in Xiamen, China. Coast. Manag. 35, 289–303.
Lu, X., Liu, H., Yang, Q., 2000. Wetlands in China: feature, value and protection. Chin. Geogr. Sci. 10 (4), 296–301 (in Chinese).
Ma, M., Zhou, X., Ma, Z., Du, G., 2012. Composition of the soil seed bank and vegetation changes after wetland drying and soil salinization on the Tibetan Plateau. Ecol. Eng. 44, 18–24.
Mangi, S.C., Roberts, C.M., Rodwell, L.D., 2007. Reef fisheries management in Kenya: preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators. Ocean Coast. Manag. 50 (5–6), 463–480.
Mantel, N., 1967. The detection of disease clustering and a generalized regression approach. Cancer Res. 27, 209–220.
Marques, J.C., Basset, A., Brey, T., Elliott, M., 2009. The ecological sustainability Trigon. A proposed conceptual framework for creating and testing management scenarios. Mar. Pollut. Bull. 58 (12), 1773–1779.
Martins, J.H., Camanho, A.S., Gaspar, M.B., 2012. A review of the application of driving forces – pressure – state – impact – response framework to fisheries management. Ocean Coast. Manag. 69, 273–281.
Mitsch, W.J., Gosselink, J.G., 2007. Wetlands, fourth ed. John Wiley and Sons, New York, NY.
OECD, 1993. Report of OECD Core Set of Indicators for Environmental Performance Reviews (Paris).
Pinto, R., de Jonge, V.N., Neto, J.M., Domingos, T., Marques, J.C., Patrício, J., 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. Ocean Coast. Manag. 72, 64–79.
Richards, J.A., Jia, X., 2006. Remote Sensing Digital Image Analysis. Springer, pp. 193–247.
Rosenberg, M.S., Anderson, C.D., 2011. PASSaGE: pattern analysis, spatial statistics and geographic exegesis. Version 2. Methods Ecol. Evol. 2, 229–232.
Tang, A., Liu, R., Xu, L., Wang, J., Liu, Y., 2011. Spatial heterogeneity of soil nutrients and distribution of plant community in Changyi marine ecological special protection Area. Bull. Soil Water Conserv. 31 (3), 88–93.
UNESCO, 1994. Convention on Wetlands of International Importance Especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. United Nations Educational, Scientific and Cultural Organization, Paris.
Valiela, I., Fox, S.E., 2008. Managing coastal wetlands. Science 319, 290–291.

Vymazal, J., 2008. Constructed wetlands for wastewater treatment: a review. In: Proceedings of Taal2007: the 12th World Lake Conference, pp. 965–980.
Weifang Station of Marine Environment Monitoring (SOA), 2007. Communique of Changyi National Marine Specific Protection Area.
Wu, S., Zhang, Z., Chen, M., Guan, Y., 2009. Change of coastal wetlands and analysis of its driving reasons along south coast of the Laizhou Bay. Wetland Sci. 7 (4), 373–378.
Wu, X., Gao, M., Wang, D., Wang, Y., Lu, Q., Zhang, Z., 2012. Framework and practice of integrated coastal zone management in Shandong Province, China. Ocean Coast. Manag. 69, 58–67.
Zhang, J., 2006. Ecological Method and Technology. Chemical Press, Beijing.
Zhang, X., Yu, D., Feng, A., Ding, D., 2004. Restoration of degraded coastal wetlands in the Southern Laizhou Bay. Mar. Sci. 28 (7), 49–53.
Zhang, X., Zhang, Y., Sun, H., Xia, D., 2006. Changes of hydrological environment and their influences on coastal wetlands in the southern Laizhou Bay, China. Environ. Monit. Assess. 119, 97–106.
Zhang, X., Zhang, Z., Xu, Z., Gu, D., Zheng, W., 2009. Landscape pattern change and its cumulative environmental effects of coastal wetlands in southern Laizhou Bay. Chin. J. Ecol. 28 (12), 2437–2443.