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Plant Diversity Performance After Natural Restoration in Reclaimed *Deyeuxia angustifolia* Wetland

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Abstract: *Deyeuxia angustifolia* wetlands were widely distributed in the Sanjiang Plain in Northeast China. Due to strong demand for food production, large-area wetlands were reclaimed to farmlands, which threatened regional ecological security greatly. Since the 21th century, returning farmlands to wetlands was widely adopted for natural restoration in the Sangjiang Plain. As the first reflection of wetland restoration, vegetation succession of restored *D. angustifolia* wetlands should be fully assessed. In this study, vegetation investigation was carried out in three restored *D. angustifolia* wetlands with 5, 8 and 12 yr restoration, respectively. Meanwhile, a natural *D. angustifolia* wetland was selected as reference wetland. Results showed that community composition changed greatly and there was visible community succession. Community dominant species changed from composite to gramineae as restoration time increasing. At first, weeds community appeared in the restored wetlands, especially the xerophytes developed to the pioneer species rapidly. And then, mesophytes and wetland species became the dominant species in the restored wetlands. Finally, wetland species, especially *D. angustifolia,* occupied the dominant position of restored community. Shannon-wiener index (H) and Simpson index (D) both decreased to close to natural *D. angustifolia* wetlands. Compared with natural *D. angustifolia* wetland, species composition and diversity in restored wetlands were more complex and higher. As restoration time increasing, there were not significant differences between community characteristics of restored wetlands and natural wetland. All these suggested that vegetation in reclaimed *D. angustifolia* wetland could be restored naturally, but its restored period is 10 yr at least. From another angle, it is important to protect current natural wetlands.

Keywords: reclaimed *Deyeuxia angustifolia* wetland; community composition; plant diversity; natural restoration

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1 Introduction

Wetlands, which are natural landscapes with high biological productivity and rich biodiversity, have a variety of ecological functions and social values (Moore, 2001; Yang et al., 2016). With the requirements of human civilization, many wetlands were drained off for farmlands round the world during the twentieth century (House et al., 1999; Mitsch and Day, 2006; Chen et al., 2007). In the process of wetland reclaimed, wetland areas de-

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creased, biodiversity lost greatly, and their eco-functions also declined even disappeared (Koroglu, 2016; Roy et al., 2016). Wetland reclaimed resulted in a series of serious impacts on regional ecological, economic and social sustainable development (Sparks, 2001; Zhang et al., 2004; Wang et al., 2012). Therefore, conservation and restoration of reclaimed wetlands were considered to be critical environmental hotspots globally (Williams, 1994; Cao and Mu, 2014; Roy et al., 2016).

Ecological restoration of wetland aimed to re-establish the ecological structure and functions of degraded wetland; re-install ecosystem functions and services and maintain biodiversity by restraining elements degradation (Maleki et al., 2018; Welsh et al., 2018). Most wetland restoration focused on three key components: hydrology, soil and biology reparation (Wang et al., 2012; Lisius et al., 2018), wherein plants were the essential part of wetland structure and function. It was the most susceptible to be destructed and the most intuitive factor in recovery. Thus, vegetation restoration is acting as a crucial step of wetland restoration.

Vegetation restoration of wetland was directly reflected by changes of plant community composition and plant diversity (Verhagen et al., 2001). Therefore, plant community composition and diversity restoration is widely used to evaluate ecological recovery (Caçador et al., 2013). Most documents have reported that species diversity could reach the desirable level after natural restoration, species of wetland plants increased markedly with restoration time increasing, but terrestrial species decreased sharply (Wang et al., 2015). However, not each natural restoration could reach its target (Toth, 2010; 2015). In reclaimed wetlands, native plants were taken place by crops and species diversity dramatically declined attributing to constraints such as loss of seed bank which was resulted from long time tillage (Wang et al., 2017). Thus, it is urgent to better understand the development of plant communities during the natural restoration of reclaimed wetland.

The Sanjiang Plain was located in the northeastern Heilongjiang Province of China, and comprised one of the richest areas of globally significant biodiversity in China. The Sanjiang Plain is also an important wetland area of China. Its freshwater wetlands were typical and representative in China, even in the world. In 1954, wetlands covered more than 32% of this area. Since then wetlands in the Sanjiang Plain have been reclaimed mostly for soybean cultivation. After more than 40 yr cultivation, reclamation rate rose from 7.22% in 1949 to 41.99% in 2000 (Liu and Ma, 2001). By 2005, cropland occupied 51.17% of the total land area, and became the dominant landscape of the Sanjiang Plain (Wang et al., 2009). Wetland reclamation has resulted in serious ecological consequences (Gao et al., 2018). Wetland function and biodiversity damaged, rare and endangered plants reduced and floods took place frequently (Zeng et al., 2006; Wang et al., 2010; Guo et al., 2014). Therefore, restoration of reclaimed wetland became particularly urgent in the Sanjiang Plain. Recently, large areas of cropland have been uncultivated for years to restore to wetland naturally. However, could cropland be restored to wetland successfully? How long to restore wetland vegetation community? What will happen to the vegetation composition and diversity? In order to answer these questions, a field experiment replacing time with space was carried out in three restored wetland which were restored in different time in the Sanjiang Plain. Dynamic rules of plant community's species composition and α-diversity during the restored process were analyzed. Study results could supply basic data and scientific evidence for restoration of degraded wetland and protection of natural wetland in Northeast China.

2 Material and Methods

2.1 Study area

The study area is located at the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Sciences (47°35′N, 133°31′E) in Tongjiang City of Heilongjiang Province, China. The elevation of the study area is about 55.4–57.9 m above sea level with a gradient of 1∶5000. The lowest, highest and annual mean air temperatures are from −18℃ to −21℃, 21℃ to 22℃ and 1.6℃ to 1.9℃, respectively. The freezing period is up to five months and the nadir is 190 cm below ground. The average annual precipitation is 565−600 mm, of which more than 60% takes place from June to August. The integrated experimental field area of Experimental Station is about 105 ha, and its dominant wetland type is natural wetland. In addition, there are also paddy (6.6 ha), dry farmland (7.0 ha), and restored wetland with different time. Marsh types, vegetation types and soil types of the experimental field are representative in the Sanjiang Plain (Xu et al., 2013). All in all, the Sanjiang

Mire Wetland Experimental Station could be regarded as a microcosm of the Sanjiang Plain. It provided a perfect condition for us to learn the restoration process of reclaimed wetland.

Three restored wetlands were reclaimed at the same time in 1980s; its former community was *Deyeuxia angustifolia* community and it was restored as a result of national policies and idea of wetland conservation. Wetland 1 (W1) was restored in 1996, wetland 2 (W2) was restored in 2000, and Wetland 3 (W3) was restored in 2003 (Fig. 1). The whole process was in natural condition without any humans' disturbances. The reference natural wetland (N) is located in the south of restored wetland (Fig. 1).

2.2 Data collection

2.2.1 Plants sampled in natural D.angustifolia wetland

Natural *D. angustifolia* wetland (N) was located in the south of proving-ground. Distance between natural and restored wetlands was 1000 m. Because the community composition and distribution of *D. angustifolia* natural wetland were uniform and stable, three 1 m × 1 m of fixed points were laid at the edge of natural *D. angustifolia* wetland to avoid secondary interruption. Distance of each fixed point was 20 m. Another three random samples (1 m × 1 m) were placed evenly in the vicinity of each fixed-point.

2.2.2 Plants sampled in three restored wetlands

According to area of restored wetlands, four 1 m × 1 m fixed plots were placed in W1, and five 1 m × 1 m fixed plots were placed in W2 and W3, respectively (Fig. 2). The rest experiment setting was same with natural wetland.

All data was sampled in August because the plants grew well and could be easily identified in this period. Plant species, density, height and coverage were

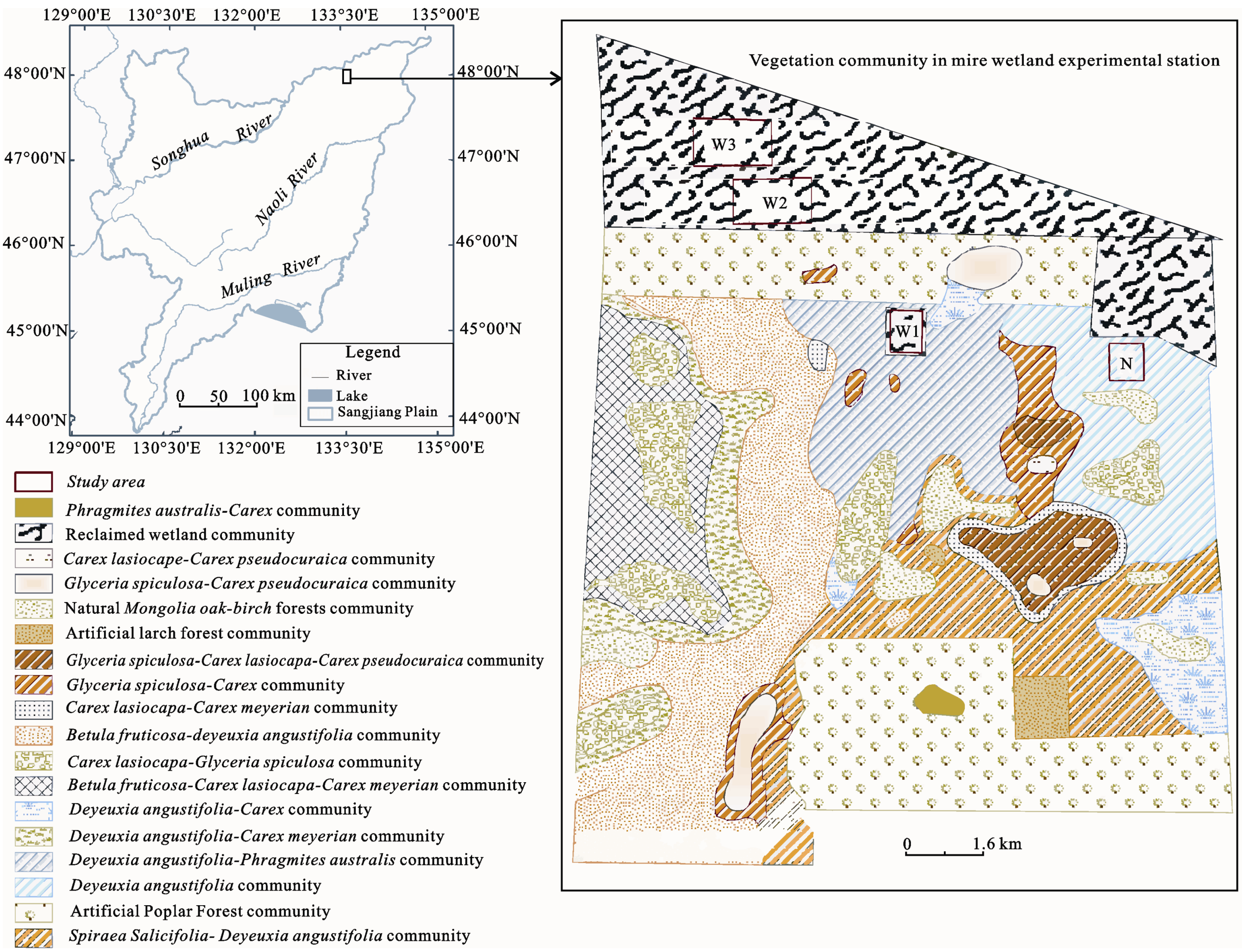

Fig. 1 Study area distribution and its vegetation feature. N, Natural *D. angustifolia* wetland; W1, wetland with 5 years restoration; W2, wetland with 8 years restoration; W3, wetland with 12 years restoration; N, natural wetland

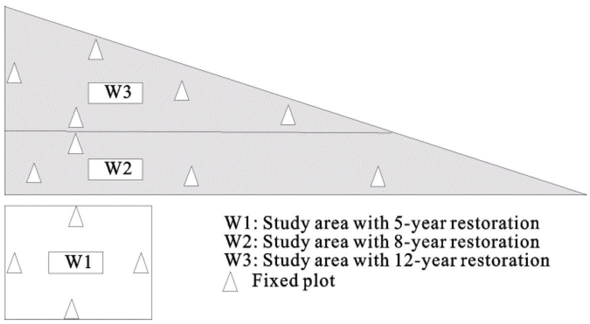

Fig. 2 Distribution of fixed sample plots in restored wetlands in study area

recorded. Additionally, the same sampling routes were adopted each time to reduce excessive interference during sampling.

2.3 Data analysis

In order to compare with the previous work, diversity indices were adopted to evaluate plant changes in the process of reclaimed wetland restoration. Important value (*IV*) was used to indicate the composition and structure of plant species along restoration stages. Shannon-wiener index (*H*), Richness index (*R*), and Simpson index (*D*) were used to describe species diversity changes. (Dong et al., 1996; Yue, 1999). Similarity index (*I*) was selected to compare the succession of each community.

$$IV = RH + RC + RF \quad (1)$$

where *IV* is the important value; *RH* is the relative density; *RC* is the relative coverage; *RF* is the relative frequency.

$$R = S \quad (2)$$

$$H = -\sum_{i=1}^{n}(P_i \times \log P_i) \quad (3)$$

$$D = \sum_{i=1}^{n}(n_i - 1)/N(N-1) \quad (4)$$

where *S* is total number of species, P_i is relative abundance of species '*i*', *N* is total number of individuals of all species, n_i is number of individuals of species '*i*'. Similarity index (*I*), using Sorenson's index:

$$I = 2c/(a+b) \times 100 \quad (5)$$

where *a* is the number of species in wetland with a-year restoration; *b* is the number of species in wetland with *b*-year restoration; *c* is the number of common species between two restored wetlands.

All data analyses were performed with the software package SPSS 16.0. LSD multiple comparisons analysis method ($P \leq 0.05$ level) was used to verify the species diversity difference among plant communities.

3 Results

3.1 Vegetation composition and structure

Investigation results showed that the dominant species changed from Composite to Gramineae as restoration time increasing (Table 1). Twenty two higher plants were found in W1, which belong to 13 families and 21 genera. The top four IV plants were *Artemisia stolonifera*, *D. angustifolia*, *Lycopus lucidus*, *Ixeris chinensis*. Twenty two higher plants were found in W2, belonging to 13 families and 19 genera. The top four Important Value plants were *D. angustifolia*, *A. stolonifera*, *Lathyrus palustris* and *Artemisia integrifolia*. We found 27 species in W3, which belonging to 15 families and 23 genera. The top four important value plants were *D. angustifolia*a, *A.integrifolia*a, *L. palustris* and *Trifolium lupinaster*. Eleven higher plants were found in natural *D. angustifolia* wetland, belonging to 7 families and 11 genus. The top four important value plants were *D. angustifolia*, *A. stolonifera*, *Sanguisorba tenuifolia* and *Phragmites communis* (Table 1).

Taking the importance value > 0.50 as the dominant species, 0.30–0.50 as the sub-dominant species as a criteria, we can find that: 1) for the natural wetland, *D.angustifolia* was the absolute dominant species; 2) in wetland with 5 yr restoration (W1), *A. stolonifera* was the dominant species, *D. angustifolia* became sub-dominant species; 3) in wetland after 8 yr restoration (W2), *D. angustifolia* became dominant species again with *A.stolonifera* as sub-dominant species; 4) in wetland after 12 yr restoration (W3), *D. angustifolia* became absolute dominant species and the community became a pure community which was similar with natural *D. angustifolia* wetland.

3.2 Species richness

Results of species richness (Fig. 3) demonstrated that as restored time increasing, species richness declined gradually to close to richness of natural wetland. Species distribution in W1 fluctuated dramatically, the maximum was 11 plants/m^2 while the minimum was 4 plants/m^2, and its species richness was 7.78 plants/m^2.

Table 1 Species, Family and Genus of the top four important value plants in wetlands with different restoration time

Wetlands	Plant Specie	Family	Genus	Important value
W1	*A. stolonifera*	Composite	Artemisia	0.75
	D. angustifolia	Gramineae	Small Reed	0.35
	L. lucidus	Labiatae	Lycopus	0.21
	I. chinensis	Composite	Sonchus	0.14
W2	*D. angustifolia*	Gramineae	Small Reed	1.09
	A. stolonifera	Composite	Artemisia	0.39
	L. palustris	Leguminosae	Lathyrus Linn.	0.09
	A. integrifolia	Composite	Artemisia	0.09
W3	*D. angustifolia*	Gramineae	Small Reed	1.33
	A. stolonifera	Composite	Artemisia	0.27
	L. palustris	Leguminosae	Lathyrus	0.12
	T. lupinaster	leguminosae	trifolium	0.11

Notes: W1, wetland with 5 yr restoration; W2, wetland with 8 yr restoration; W3, wetland with 12 yr restoration; N, natural wetland

Species number of each quad in W2 was less than that in W1, but more even, and the species richness was 6.83 plants/m^2. Species number in W3 also fluctuated dramatically, there was even a single species in partial quad, and the species richness reduced to 5.73 plants/m^2. In natural wetland, plant was well-distributed, and the species richness was only 4.67 plants/m^2. One-way analysis of variance (ANOVA) indicated that species richness were significant different between W1, W2 and natural wetland (P = 0.000). However, there was no significant difference between natural wetland and W3 (P = 0.131). There was also no marked difference between W1 and W2 (P = 0.091), but both them were marked different with W3 (P = 0.000). All these illustrated that species richness of restored wetlands became more and more similar with that in natural wetland as restoration time increasing.

3.3 Plant diversity

As shown in Fig. 4, Shannon-wiener index of restored wetland reduced along the increasing restoration time. Simpson Dominance Index of restored wetland first reduced and then increased along the increasing restoration time. Shannon-wiener Index and Simpson index of restored wetland were still higher than that of natural wetland. Simpson Dominance Index was less fluctuation than Shannon-wiener Index of restored wetland.

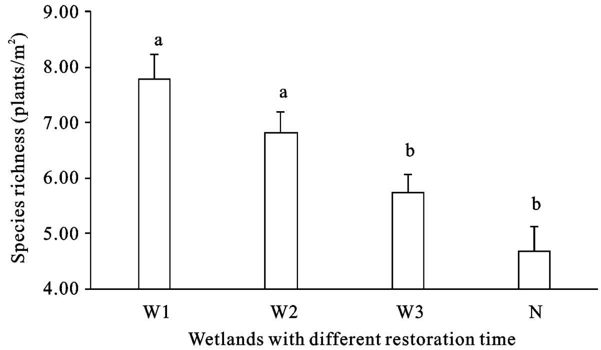

Fig. 3 Species richness of natural wetland and restored wetlands. Lowercase represent differences among restored wetlands and natural wetland. Natural *D. angustifolia* wetland; W1, wetland with 5 yr restoration; W2, wetland with 8 yr restoration; W3, wetland with 12 yr restoration; N, natural wetland

One-way analysis of variance (ANOVA) showed that Shannon-wiener index of natural *D. angustifolia* community has a significant difference with community in W1 and W2 (P = 0.000). However, species diversity of natural community was not different with that in W3. Species diversity in different restored wetland was different with each other. Simpson index demonstrated that plant distribution in W1 was marked different with W2, W2 and natural community, but there were not significant differences among W2, W3 and natural wetland (Table 2). All above suggested at the beginning of wetland restoration, species diversity increased but their distribution was uneven. With restoration increasing, species diversity reduced with an even distribution and this phenomenon was close to natural wetland.

3.4 Community similarity

Community similarity increased with restoration time increasing. A total of 11 common species were found

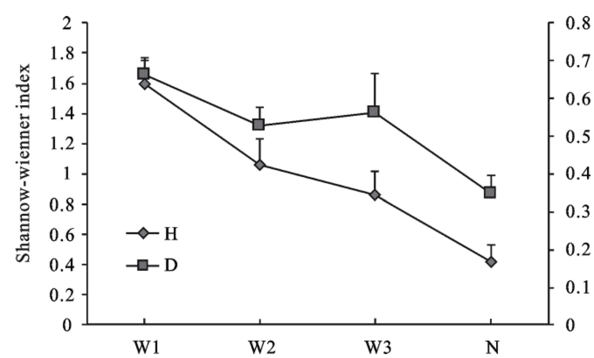

Fig. 4 Shannon-wiener and Simpson index of plant community of reclaimed *D. angustifolia* wetland with different restoration time. W1, wetland with 5 yr restoration; W2, wetland with 8 yr restoration; W3, wetland with 12 yr retoration; N, natural wetland; *H*, Shannon-wiener index; *D*, Simpson index.

Table 2 Differences of Shannon-wiener and Simpson index among natural *D.angustifolia* wetland and restored wetlands

Wetlands		Shannon-wiener index	Simpson index
N	W1	–0.2897*	–0.0013*
	W2	–0.1711*	–0.0004
	W3	–0.0570	–0.0005
W1	N	0.2891*	0.0013*
	W2	0.1186*	0.0009*
	W3	0.2328*	0.0008*
W2	N	0.1711*	0.0004
	W1	–0.1186*	–0.0009*
	W3	0.1141*	–0.0001
W3	N	0.0570	0.0005
	W1	–0.2328*	–0.0008*
	W2	–0.1141*	0.0001

Notes: * indicates significant difference ($P < 0.05$); W1, wetland with 5 yr restoration; W2, wetland with 8 yr restoration; W3, wetland with 12 yr restoration; N, natural wetland

between W1 and W2, while 17 common species were found between community restored for W2 and W3. The community similarity between W1 and W2 was 50%, and the similarity between W2 and W3 was 75%. Above results illustrated that there must be some internal relationship during the process of vegetation restoration.

4 Discussion

4.1 Plant diversity changes during the process of reclaimed wetland restoration

Self-design theory and secondary succession theory held that vegetation could be restored naturally in the case of micro-interrupt. Plant could succession in accordance with the development track automatically until to the pre-damaged level (Zhou et al., 2001). Therefore, the pre-damaged community decided the process of vegetation succession during the restoration of wetlands. In the abandoned croplands in Ruanliang, vegetation restoration experienced three community types, including weeds community, the sub shrub *Artemisia ordosica* community, and the perennial grass community. However, the abandoned croplands in Yingliang experienced another three community types, including weeds community, perennial *Stipa bungeana* with *Artemisia frigida* community, and *S. bungeana* community (Cai et al., 2018). Even in the same region, uncultivated natural vegetation in Yingliang and Ruanliang areas were respectively taken as contrasting, which affected the final restoration results. The important value of dominant species in abandoned croplands during the restoration process changed significantly. Species diversity also became more and more close to the un-interrupted wetlands (An et al., 2018). Wetland species increased, but terrestrial species reduced to zero as restoration time increasing. In this study, Gramineae, Composite, Rosaceae and Leguminosae were the most dominant in each wetland. Plant showed a clearly succession. At first, weeds community appeared in the restored wetlands, especially the xerophytes developed to the pioneer species rapidly. And then, mesophytes and wetland species became the dominant species in the restored wetlands. Finally, wetland species occupied the dominant position of restored community. This result is agreed with previous findings.

May (1972) considered that there were complex relationships between diversity and stability. Higher diversity did not mean higher stability, and similarly, the lower diversity did not mean instability. In plateau wetland ecosystems, plant diversity is a useful indicator of stability condition of wetland community (Li et al., 2014). Carvalho's research (Carvalho et al., 2013) suggests that biodiversity is vital to wetland functioning and stability. While in some marsh wetlands and coastal wetland plant community, their plants were more single and their systems were more stable. However, in matured plant community, experienced over 10-year restoration, significant reduction was found in pant diversity and species, and species tend to obligate and facultative wet (Nedland1 et al., 2007; Wang et al., 2012). In our study, early restored diversity was higher than the late, but the relationship between diversity and stability was unclear during the restoration process. We could only find that in the natural *D. angustifolia* wetland, *D. angustifolia* was an absolute dominant species for one century (Lou et al., 2006). Therefore, species diversity reduction should be considered as a positive phenomenon in the restoration of reclaimed wetlands.

4.2 Factors affecting the restoration of vegetation in reclaimed wetland

Many factors would restrain vegetation restoration of degraded wetlands, including water supplement (Guo et al., 2017), nutrient availability (Mitchell et al., 2015), cultivation period (Barrett and Watmough, 2015), seed banks (Liu et al., 2005; Bai et al., 2014), restoration time and so on (Lemein et al., 2017). Usually, vegetation would be more and more similar with target wetlands as restoration time increasing. However, it is too difficult to restore to un-interrupted wetlands without seed banks (Wang et al., 2017). Therefore, in reclaimed wetland, cultivation age, seed banks and restoration time would be the most important three elements influencing vegetation restoration. Seed bank is a crucial component of ecological restoration, particularly in abandoned farm land. It provides seeds for the regeneration of plant communities, and can be of value in the natural restoration of farm fields to wetlands if the seeds have survived from cultivation. Long time farming (> 10 yr) could result in main wetland species disappear from seed bank, and this could explanation why some wetland species did not exist at restoration wetland, even with a long time restoration (Wetzel et al., 2001; Wang et al., 2015). Whether or not species will naturally re-establish in formerly farmed lands depends to a large extent on the availability of seeds in the seed bank. Particularly, duration of farming influenced seed bank greatly. In the Sanjiang Plain, effects of shorter periods of farming (less than 5 yr) on seed bank are negligible. Once farming age is more than 16 yr, it is difficult to keep enough seed bank of wetland species to restore wetlands naturally (Wang et al., 2017). Wetland natural restoration also need time to get its original level with enough seed bank. Paddy need only 5 yr to be restored as a wetland, but their species composition, community structure and pace of succession were influenced by the site context and patch size (Cook et al., 2005; Matthews and Endress, 2010; Park et al., 2014). However, if seed bank is lost, vegetation would be difficult to reach to the original level before reclamation even be restored for 60 yr or longer time (Moreno-Mateos et al., 2012; Stroh et al., 2012). In this study, vegetation was restored successfully even though study area was reclaimed over than 30 yr. As time passing, species number increased first and then reduced. Species richness and Shannon-wiener index both reduced as time increasing, and vegetation distribution was more even. Community similarity rose greatly comparing with natural wetland. After 8 yr restoration, there were not many common species between restored wetland and natural wetland, but there were many common species restored for 12 yr. Hence, it could be deduced that reclaimed wetland can be restored naturally, but need 10 yr at least. This result is contrast with Wang et al.'s (2015) study because our reclaimed wetland is not far away from natural wetland which may provide seeds continuously for the abandoned farmland. While, other study areas were surrounded by croplands. Our result also verified the importance of seeds bank in the process of reclaimed wetland restoration.

Besides, natural *D.angustifolia* community was found to appear a marked degradation trends compared with researching results in 1980s (Lou et al, 2006). Except *D. angustifolia* was still the absolute dominant species, its associated species had been significantly different. Many wetland species degraded even disappeared. Therefore, a present natural wetland must be selected as a reference target during the process of wetland restoration. On the other hand, natural wetland protection may be more important and valuable under current environment.

5 Conclusions

In recent years, restoration of the reclaimed wetland was paid more and more attentions. In this paper, some results were identified:

(1) Vegetation of reclaimed wetland could be restored to un-reclamation level even though it was cultivated for more than 30 years.

(2) Vegetation succession was marked and closed to natural vegetation as restoration time increasing. Its restoration period is 10 years at least.

(3) During the restoration, terrestrial species gradually changed to wetland species. Community's dominant species greatly changed from *A. stolonifera* to *D. angustifolia,* and the associated species changed from xerophytes and mesophytes to mesophytes and hygrophytes. Finally, restored wetland became a pure community with *D. angustifolia* as absolute dominance, and became more similar to natural *D. angustifolia* community.

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