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ORIGINAL PAPER

Changes of plant species diversity and biomass with reclaimed marshes restoration

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Abstract Wetland restoration had been implemented for more than two decades in Sanjiang Plain, Northeast China. To assess the restoration efficiency of wetland vegetation, we investigated plants composition of community, plant species diversity and aboveground biomass of restored sites in a chronosequence of restoration (1, 2, 3, 6, 8, 11, 15 and 25 years) in the Sanjiang Nature Reserve. As comparison, we also investigated the same factors in a cropland and a natural marsh adjacent to the restored sites. The results showed that wetland plant species can invade quickly after croplands were abandoned when there were suitable hydrology conditions. On the early stage of the restoration, weeds were main plant species in the restored sites. Wetland species appeared at the same time but differed from the dominant species from the adjacent natural marshes. Common native wetland species could dominance the community after 3-year restoration. Species richness and diversity increased on the early stage, and then decreased to the similar level of the natural marsh with the extension of restoration. Plant biomass could restore easier than the species composition and diversity. Our results indicated that plant species composition and diversity of abandoned reclaimed wetlands can restore gradually by natural succession in Sanjiang Plain. However, 25-year restoration site had similarity index of only 56% with the natural marsh, which revealed that two decades are not enough for complete restoration of vegetation.

Keywords Plant species composition · Richness index · Shannon–Wiener index · Similarity index · Wetland restoration

Xin Jin and Xiaoxin Sun have contributed equally to this research.

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Introduction

Wetland is one of the landscapes with most biodiversity, and also the most important habitat where people live (Mitsch and Gosselink 2015). Wetlands provide a variety of services for human beings, including water regulation, water supply, climate regulation, soil formation, nutrient cycling, biological control, and so on (Costanza et al. 1997). However, most of the wetlands disappeared or are degrading by disturbance all over the world, especially in China (State Forestry Administration of China 2015). Wetland degradation refers to a series of deterioration phenomena of wetland biotic and abiotic environments, such as the destruction of ecosystem structure, the decrease of biodiversity, the decline of ecosystem productivity and other functions, and the gradual loss of wetlands (Gao et al. 2008). To protect and sustainably utilize wetlands, how to restore degraded wetlands is becoming more and more important in the protection and management of wetlands (Cui and Liu 1999). Besides choosing better restoration methods and techniques, how to determine the degree of wetland restoration is also an important issue should be considered in wetland restoration projects (Wu and Wang 2006; Cui et al. 2011).

Vegetation is the primary producer of wetland ecosystem, which plays an important role in supporting the structure and function of this ecosystem. Vegetation directly participates in the matter cycle of wetland ecosystem by providing food and habitat for other organisms (Mitsch and Gosselink. 2015). It can also indicate changes of the external environment by the plant characteristics (Doughty et al. 2015; Wang et al. 2017a, b). Therefore, vegetation is the key factor to maintain wetland ecosystem health and stability. Vegetation restoration is one of the key contents in the assessment of the restoration efficiency of degraded wetland (Aronson and Galatowitsch 2008). Plant monitoring for wetlands restoration includes plant composition (Pfeifer-Meister et al. 2012; Metthea et al. 2014), community structure (Yang et al. 2002), species diversity (Hopple and Craft 2013; Audet et al. 2015), plant cover (Henry and Amoros. 1996; Reid and Naeth. 2005), biomass (Miller and Fujii 2010; Yang et al. 2012) and productivity (Craft et al. 1999; Ren et al. 2011), and so on. Continuous monitoring of vegetation during wetland restoration can provide objective evaluation of wetland organisms and their habitat restoration efficiency. This work can also provide a reference for decision makers of ecological management.

Sanjiang Plain lies on northeast Heilongjiang Province. It is one of the main marsh distribution areas in China because of concentrated rainfall, low terrain and poor drainage of clay soil (Liu 2005). More than 80% of the Sanjiang Plain were wetlands before 1949, thereafter, most of the wetlands converted to farmlands because the increased demand for food by national population development (Wei et al. 2014). One research showed that wetlands areas decreased by 77% between 1954 and 2005 and only 810, 000 hm^2 marshes exist in this region (Wang et al. 2011).

With the gradual decline of wetland area in Sanjiang Plain, the environmental quality and ecosystem service function decreased (Zhao et al. 2008). To prevent the further loss of wetlands and reduce the adverse effects of environmental degradation, the government gradually strengthened the protection and restoration of wetlands in Sanjiang Plain. A number of national and provincial wetland nature reserves have been gradually established (Ma et al. 2003). Meanwhile, a series of wetland ecosystem restoration projects were carried out in Sanjiang Plain (Li et al. 2006). How about the wetlands restoration efficiency in this area after more than 20 years of restoration? We chose a chronosequence of wetlands restoration (1, 2, 3, 6, 8, 11, 15 and 25 years) to investigate the plants composition of community, plant species diversity and aboveground biomass. Our objectives were to (1) detect the variation of plant composition of community during wetlands restoration; (2) assess whether plant species diversity could be restored by natural succession method after farmlands were abandoned; (3) reveal if time of two decades is enough for vegetation recovery in reclaimed wetlands restoration.

Materials and methods

Site description

This research was conducted in Sanjiang Nature Reserve in northeast Sanjiang Plain in Heilongjiang Province. The area of Sanjiang Nature Reserve is 198,100 ha (47° 26′ 00″–48 ° 22′ 50″ N; 133° 43′ 20″–134° 46′ 40″ E). The region is located in the temperate climate zone, with a mean annual temperature of 2.5 °C and mean annual precipitation of about 558 mm. Sanjiang Plain has the largest freshwater marshes in China. The main communities include *Carex* spp. marsh, *Phragmites australis* marsh, *Carex* spp.—*Deyeuxia angustifolia* marsh and *D. angustifolia* wet meadow.

Some of these marshes were converted to cropland before 1995. After the Nature Reserve was established in 1995, parts of the reclaimed marshes were restored. In July 2016, we chose the sites restored 1, 2, 3, 6, 8, 11, 15 and 25 years to investigated natural vegetation recovery. All the restored sites were planted soybean for about 10 years before they were abandoned. Natural succession method was used without human disturbance after croplands were abandoned. All the restored sites were adjacent to natural marshes and were affected by natural floods. We also investigated a soybean cropland and an undisturbed marsh dominated by *Carex schmidtii* and *Deyeuxia angustifolia* to compare the vegetation restoration efficiencies.

Date collection

We chose three plots in each site across the chronosequence of restoration (1, 2, 3, 6, 8, 11, 15 and 25 years), the soybean cropland and the natural marsh. We established one 1 m × 1 m quadrats in each of the plots. Plant species composition and characteristics including number, cover and height of each species were recorded in each quadrat in mid-July. All plants were harvested above the ground surface in each plots and brought back to the laboratory for drying to calculate aboveground biomass.

Calculation and statistical analysis

We used important value to assess the importance of plant species in each plots. We use the richness, Shannon–Wiener index and evenness index to describe the plant species biodiversity. We use similarity index to assess the effectiveness of plant restoration.

We calculated important value, richness index, Shannon–Wiener index, evenness index and similarity index in each site according to the format below (Ma and Liu 1994; Ma et al. 1995; Chen and Yang 2014):

$$\text{Important value} = \frac{(RD + RC + RH)}{3} \times 100, \quad (1)$$

where RD is the relative density, RC is the relative coverage, and RH is the relative height.

$$\text{Richness index} = \text{the number of plant species in each plot} \quad (2)$$

$$\text{Shannon–Wiener index} = -\sum p_i \ln p_i \quad (3)$$

Evenness index of J_{sw}:

$$J_{sw} = \frac{-\sum p_i lnp_i}{lnS} \quad (4)$$

where P_i is the relative important value of the ith species, $P_i = n_i/N$; n_i is the important value of the ith species; N is the sum of total species individuals.

Similarity index of C_s:

$$C_s = \frac{2j}{a + b} \times 100 \quad (5)$$

where a is the number of species in the restored sites or in the cropland; b is the number of species in the natural marsh; j is the number of species both in the restored sites or in the cropland and in the natural marsh.

Data from three 1 m × 1 m plots were averaged. ANOVA analysis (Duncan test) was used to compare the differences of plant species diversity and aboveground biomass between cropland, restoration sites and natural marsh. Differences were considered to be significant when the P value is less than 0.05.

Results

Plant species composition of community

A total number of 52 species were found in all the research sites, including 3 sedges, 1 rush, 11 grasses, 35 forbs and 2 shrubs. Of the 52 recorded species, 4 species were found in the soybean field, 8 species were found in the natural marsh, and 49 species were found in the restored sites (Table 1).

Cropland was dominant by soybean (*G. max*), companied by few weeds. During the early stage of 1–2 years restoration, there were no dominant species in plant community of the restored sites. Plant species with important value over 10 were two weeds of *Echinochloa caudate* and *E. crusgalli*, and three native wetland species of *Scirpus triqueter*, *Eragrostis pilosa* and *E. minor*. Weeds also included *Setaria viridis*, *Bidens bipinnata*, *Polygonum persicaria*, *Rumex amurensis*, and so on, which were about total 10 common weed species but most of them with important values below 5. After 3-year restoration, a most common wetland species in Sanjiang Plain, *Deyeuxia angustifolia*, became dominant gradually in the restored sites. After 6-year restoration, weed species decreased rapidly. Both native species *D. angustifolia* and *Carex schmidtii* dominant the restored sites, their combined important value were more than 50 (Table 1).

We used plant community similarity index between the restoration sites and the natural marsh to assess the recovery of plant composition in community. We found that the similarity index increased with restoration years. Similarity indexes were zero in soybean cropland and 1 year restoration sites. These values were ranged from 17 to 50% in the 2–8-year restoration sites. After 11-year restoration, similarity index was stable above 45%, and reached 56% after 25-year restoration (Fig. 1).

Plant species diversity

Plant species richness index, Shannon–Wiener index and evenness index fluctuated across the chronosequence of restoration. No increasing or decreasing trends were found of these indexes. However, investigated sites during the early restoring stage (restoring 1–3 years) had higher plant species richness index and higher Shannon–Wiener index than the natural marsh ($P < 0.05$). Two-year restoration site had plant species richness index of 10, which was the highest in all of the investigated sites. One year restoration site had Shannon–Wiener index of 1.81, which was the highest in all of the investigated sites. Though the 1 year restoration site had the highest evenness index, it was not significantly different from most of the restoration sites except restored 11- and 15-year sites. Cropland had the lowest plant species richness index, Shannon–Wiener index and evenness index in all the investigated sites. These differences were significant ($P < 0.05$) except the richness index between cropland and the natural marsh (Fig. 2).

Aboveground biomass

We observed the highest aboveground biomass in cropland ($P < 0.05$). We also found lower aboveground biomass in

Table 1 Plant species composition and important value in restored sites, natural marsh and soybean field (mean ± SE)

Plant species	CL[a]	R1	R2	R3	R6	R8	R11	R15	R25	NM
Sedges										
Carex schmidtii				4.72 ± 6.67	28.76 ± 4.92		24.06	10.43 ± 7.41	41.98 ± 6.03	57.72 ± 10.85
Cyperus amuricus						1.8 ± 2.54				
Scirpus triqueter		21.95 ± 14.39	6.22 ± 5.84	9.82 ± 13.88		1.45 ± 2.05		0.8 ± 1.13		
Rush										
Juncus effusus				0.74 ± 1.05						
Grasses										
Arthraxon hispidus								8.76 ± 9.71		
Beckmannia syzigachne		7.38 ± 10.44								
Deyeuxia angustifolia			2.74 ± 3.87	31.21 ± 22.64	48.70 ± 5.6	53.98 ± 1.19	59.3 ± 14.3	59.64 ± 6.73	36.29 ± 6.82	24.37 ± 0.87
Deyeuxia langsdorffii				9.84 ± 6.97						
Echinochloa caudate		17.54 ± 8.65	11.69 ± 16.53							
Echinochloa crusgalli	4.38 ± 6.19	3.97 ± 3.51	23.58 ± 16.78	3.27 ± 4.63		1.46 ± 2.07				
Eragrostis minor		4.62 ± 3.36	11.34 ± 11.15	11.9 ± 14.21		15.43 ± 5.58		1.7 ± 2.41		
Eragrostis pilosa		13.43 ± 18.99	12.02 ± 17							
Phragmites australis			3.01 ± 4.25		4.53 ± 6.41		5.01 ± 7.09			
Setaria viridis		1.7 ± 2.4	1.97 ± 2.78	1.38 ± 1.95		3.12 ± 2.21		2.99 ± 2.12		
Zizania latifolia				2.62 ± 3.7						
Forbs										
Aegopodium alpestre		1.9 ± 2.68								
Amaranthus lividus	5.03 ± 2.15									
Artemisia. leucophylla			2.77 ± 3.14							
Artemisia selengensis						4.19 ± 2.99				
Artemisia. sublata			1.2 ± 1.69							3.3 ± 4.66
Bidens bipinnata		6.26 ± 4.58	0.57 ± 0.81			2.39 ± 1.71				
Bidens maximovicziana		2.53 ± 3.58	6.29 ± 2.5							
Commelina communis	1.96 ± 2.77		0.88 ± 1.24			0.33 ± 0.47				
Conyza canadensis		4.56 ± 6.44	0.69 ± 0.98							
Glycine max	88.63 ± 10.92									
Inula japonica			0.96 ± 1.36					2.75 ± 3.89		
Kummerowia striata								0.47 ± 0.66		
Lysimachia davurica					5.58 ± 1.82				1.45 ± 2.06	
Ludwigia prostrata			4.81 ± 6.8							
Onoclea sensibilis										3.82 ± 5.40
Pedicularis resupinata								1.73 ± 2.44		
Polygonum persicaria		4.42 ± 3.53	5.04 ± 4.14	2.02 ± 2.86						
Polygonum plebejum			1.57 ± 1.11							

Table 1 (continued)

Plant species	CL[a]	R1	R2	R3	R6	R8	R11	R15	R25	NM
Polygonum strigosum								2.02 ± 2.86		
Polygonum trigonocarpum		3.28 ± 4.63								
Ranunculus japonicus			0.85 ± 1.21							
Rumex amurensis		2.61 ± 3.69	1.2 ± 1.69							
Rumex trisetifer		2.90 ± 4.11								
Sagittaria sagittifolia				2.46 ± 3.48						
Sagittaria trifolia var. angustifolia				2.17 ± 3.07						
Sanguisorba tenuifolia				2.68 ± 3.79	5.95 ± 1.55		3.11 ± 2.09		4.72 ± 3.34	
Stachys baicalensis				3.57 ± 3.12		4.26 ± 3.01		3.29 ± 4.65	3.25 ± 2.31	
Stachys chinensis						0.89 ± 1.26				
Stachys palustris							0.79 ± 1.11	0.62 ± 0.87	2.32 ± 1.66	0.57 ± 0.8
Stellaria discolor		0.96 ± 1.36				1.87 ± 2.64				
Stellaria media				5.38 ± 4.19		1.47 ± 2.08				
Stellaria radians				2.35 ± 3.33		1.09 ± 1.54				
Thelypteris palustris					3.23 ± 1.97			3.39 ± 2.06		5.28 ± 7.47
Triadenum japonicum						6.29 ± 8.9			2.25 ± 1.93	1.24 ± 1.76
Viola patrinii			0.62 ± 0.45	0.75 ± 1.06	0.27 ± 0.39		0.86 ± 0.63	1.41 ± 1.48	1.95 ± 0.51	3.7 ± 1.27
Shrubs										
Salix rosmarinifolia var. brachypoda				3.12 ± 4.41					1.12 ± 1.59	
Spiraea salicifolia					2.99 ± 4.22		6.87 ± 5.2		4.66 ± 3.35	

[a]CL represents cropland, R1, R2, R3, R6, R8, R11, R15, R25 represent the sites of different years of restoration, NM represents natural marsh. The same below

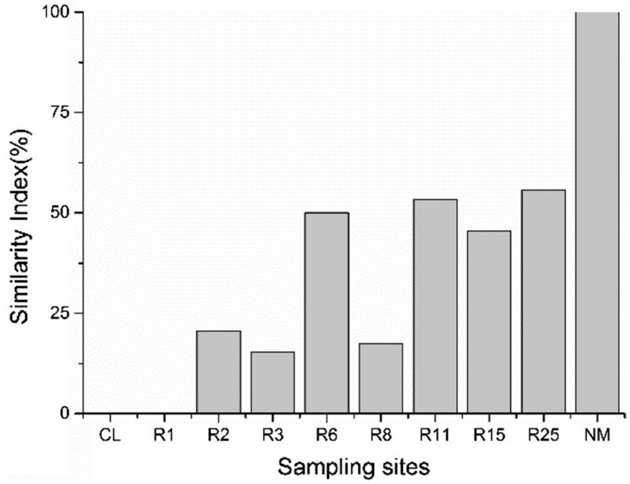

Fig. 1 Community similarity of cropland, restored sites to natural marsh

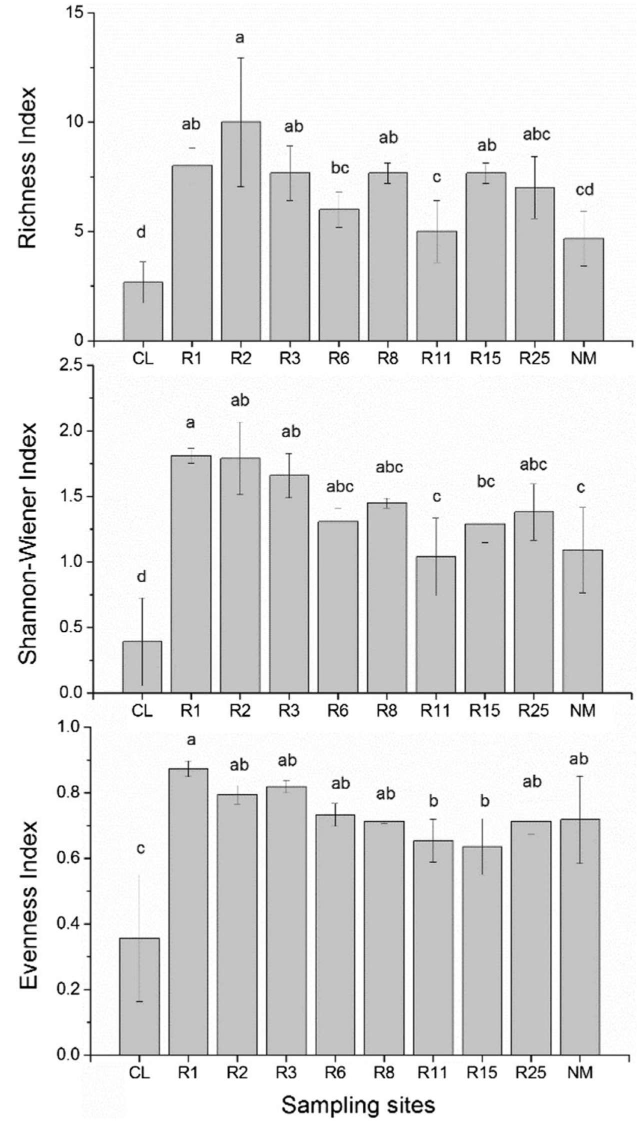

Fig. 2 Indexes of plant species diversity in cropland, restored sites and natural marsh. The error bars indicate ± SE (n = 3), different letters indicate significant differences in means

the 25-year restoration site and the natural marsh though some of the differences were not significant ($P > 0.05$). The trend of the aboveground biomass decreased with prolonged restoration time but fluctuated occasionally (Fig. 3). There were positive correlations between aboveground biomass and plant diversity indexes. However, the relationships were weak and insignificant ($P > 0.05$, Fig. 4).

Discussion

Species composition and similarity of community

Across the chronosequence of restoration, two native wetland species including *S. triqueter* and *E. pilosa*, and two weeds of *E. caudate* and *E. crusgalli* had the highest important values in the 1–2 year restored sites. *D. angustifolia*, one of the most common wetland species in Sanjiang Plain dominated the sites after 3-year restoring. Even in the early 1–3-year of restoration, the restored sites had native wetland species indicated that the cropland before restoration might have rich seed banks. However, the native plants with the most important values differed to the natural marsh revealed that these seed banks were also different to the latter. Different seed banks facilitated native plants restoration. Former studies showed that most dominant sedges (e.g., *Carex schmidtii*) and grasses (e.g. *Calamagrostis angustifolia*) survived as seeds when farming time was less than 5 years, but *Carex* species were not retained in seed banks when farming time were more than 6 years (Wang et al. 2015, 2017a, b). All the sampling sites were farmed for about 10 years in this study. Different species with the most important values in the early 2 years suggested that seed banks of both dominant sedges and grasses were changed. However, seed banks could recover quickly because our research sites were all adjacent to natural marshes. A similar study not far away from our investigated sites in Sanjiang Plain showed a different result in native dominant plant species recovery to our study (An et al. 2018). They found sedges appeared at the eighth year and *D. angustifolia* dominated in community at the thirteenth year after wetlands were restored (An et al. 2018). More early appears of sedges and dominated by *D. angustifolia* in our investigated restored sites may be induced by the wetter soil conditions because each restored sites were adjacent to natural marshes and they are hydrologically connected.

The cropland had the lowest similarity index with the natural marsh. Zero similarity means that there was no

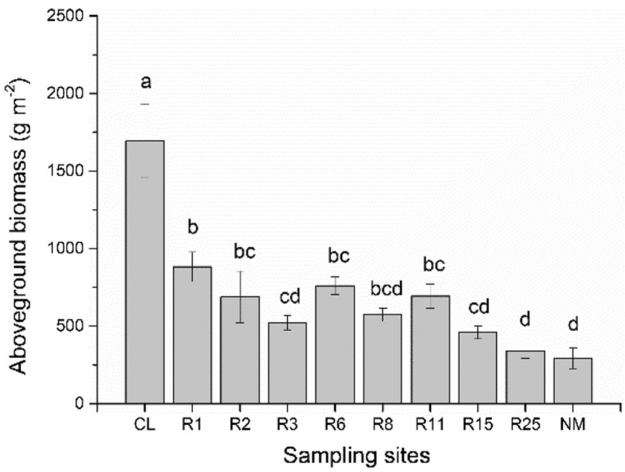

Fig. 3 Aboveground biomass of cropland, restored sites and natural marsh. The error bars indicate ± SE (n = 3), different letters indicate significant differences in means

common species among the two sites. Low similarity index of 0.118 among cropland and natural marsh was found in Xingkai Lake Natural Reserve in northeast China (Li et al. 2011). Similar results in the two studies were caused by the cropland management, mainly by herbicide and tilling eliminated most of the native wetland plant species in the cropland. Though common wetland species of *D. angustifolia* appeared and the important value were more than 30 from the third year of restoration, the similarity index was only 56% after 25-year restoration. A similar study showed that the similarity of community in 20-year restoration of *D. angustifolia* marsh in the middle Sanjiang Plain was 72.7% (An et al. 2018). Though their result was higher than ours, both of them indicated that two decades were not enough for plant composition restoration of the reclaimed wetlands in Sanjiang Plain by natural succession method. The result from a meta-analysis by restored wetlands all over the world showed that structural features of plant assemblages remained lower than undisturbed wetlands even after one-century restoration (Moreno-Mateos et al. 2012). These results revealed that complete restoration of plant species composition requires particularly long time.

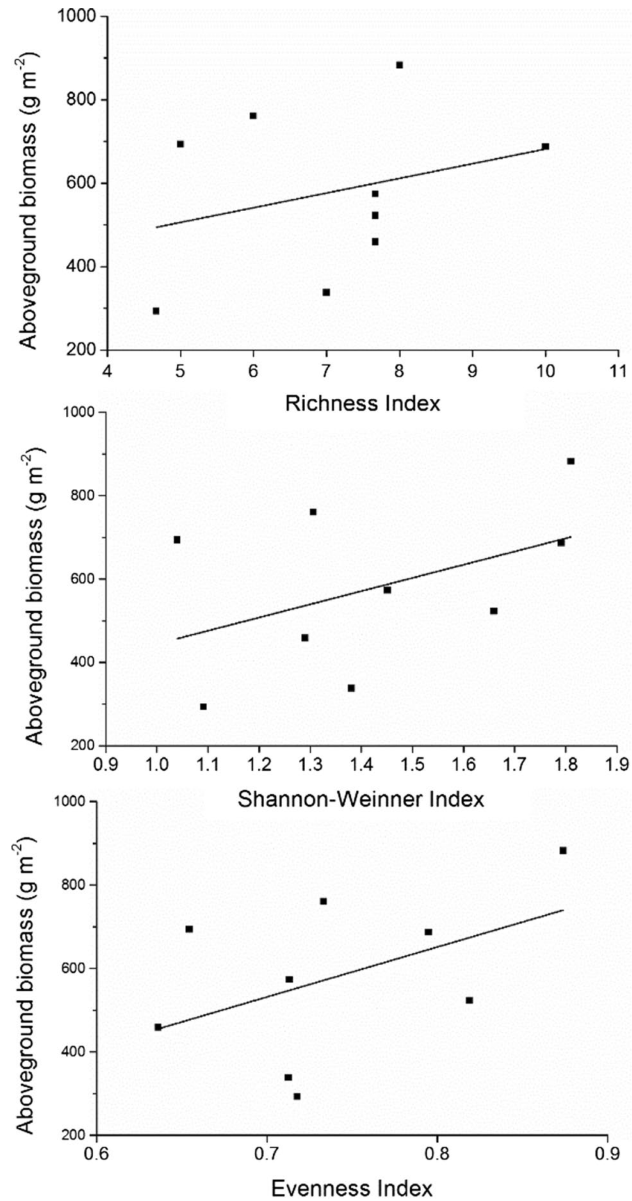

Fig. 4 Relationship between aboveground biomass and biodiversity in restored sites and natural marsh

Plant species diversity

Cropland had the lowest richness index and Shannon-Weiner index in all the investigated sites ($P < 0.05$). This is accordance with previous study because the cropland management (Yepsen et al. 2014). All restored sites have higher species richness index and Shannon-Weiner index than the cropland and the natural marsh. The differences were significant in the early 1 to 3 years ($P < 0.05$). Highest richness index was observed in the second year of restoration because both upland weeds and wetland species (both sedges and grasses) developed well in the restored sites. More species were found in the early stage of restoration in previous studies (Wang et al. 2012; An et al. 2018). One research found that 1-year restored floodplain wetland had highest richness index (Ho and Richardson 2013). One research also showed that 2-year restored wetland had highest richness index and Shannon-Weiner index (An et al. 2018). Similar results among our and other studies indicated that natural succession method may induce the similar successional trajectories of plant restoration though the restored sites may have different original farming contexts (An et al. 2018; Wang et al. 2019).

Environmental factors were important to plant species diversity restoration (Mulhouse and Galatowitsch 2003). Our investigating sites in this study were not small restored patches in large farmlands, they were all adjacent to natural wetlands. Therefore, two important factors which affect vegetation restoration were guaranteed in the restored sites. One factor is the convenience of seed dispersal. Another factor is the hydrological connectivity of wetland. Restored sites without disturbance after restoration can have similar hydrological condition with natural marshes. Flooded condition facilitated wetland species settling and plant species richness restoration (Aronson and Galatowitsch 2008; Audet et al. 2015).

Topography is also one of key factors that affect wetland vegetation succession (Zedler 2000). On the early stage of farmland were abandoned, there were ridges and furrows left by tilling in our study sites. Most of flooded water can be preserved in or drained through the furrows. Therefore, weeds mainly grew on the ridges, sedges and grasses mainly grew in the furrows. With the extension of restoration time, these ridges collapsed and flattened gradually. After several years of restoration, sedges developed and formed higher microtopography, which blocked the flow of water and prolonged the stay time of water on the ground surface. Therefore, the restored sites became wetter with the restoration time. Highland weeds became fewer and wetland plant species developed well gradually. The combined effects of the three important factors of seed dispersal, hydrological conditions and microtopography induced the changes of plant species diversity across the chronosequence of wetland restoration. Therefore, plant species diversity became more and more similar to the natural marsh with the extension of restoration, as the results from many restored wetlands in previous studies (Meyer et al. 2010; Osland et al. 2012; Pfeifer-Meister et al. 2012).

Cropland had the lowest evenness index in all the investigated sites ($P<0.05$). One-year restored site had the highest evenness index in all the investigated sites, but it was not significantly different to the other restored sites and to the natural marsh ($P>0.05$), except the 11-year and 15-year restored sites. This result indicated that anthropogenic disturbance can decrease plant evenness of community (Yepsen et al. 2014). However, the evenness can recovery well after the disturbance be ceased.

Aboveground biomass

We found the highest aboveground biomass in the cropland and were mainly caused by artificial sowing and fertilization. Across the chronosequence of wetland restoration, all restored sites had higher aboveground biomass than the natural marsh, and half of the differences were significant ($P<0.05$). Same result was found in a study covered 3–10-a restored wetland sites in the middle of Sanjiang Plain (Wang et al. 2019). These results indicated that the restoration of plant biomass and productivity were easier than the restoration of plant composition and species diversity.

Previous studies found that plant productivity is related to plant species diversity in the community in different ecosystems. For example, a large-scale subtropical forest experiment showed that richness strongly increased stand-level productivity (Huang et al. 2018). Positive relationship between diversity and productivity was also found in a long-term grassland experiment, and 16-species plots attained 2.7 times greater biomass than monocultures (Tilman et al. 2001). We also found a positive correlation between aboveground biomass and plant diversity indexes. However, the relationship was not significant ($P<0.05$). Unevenness microtopography of the wetlands (both the restored and natural wetlands) may be the reason induced the relationship of plant biomass and species diversity differed from other studies. Special high microtopography formed by sedges can only be colonized by a few dominant wetland species. These dominant wetland species occupied most of the biomass of the community thus confused the positive relationship between plant biomass and species diversity.

Conclusion

Our research found that wetland plant species composition and diversity can restored gradually by natural succession after wetlands were abandoned in Sanjiang Plain. On the early stage of the restoration, both upland weeds and wetland species existed in plots. Wetland plant species appeared in the restored sites with the important values more than 10. However, they differed from the adjacent undisturbed marsh. Common native wetland species could dominant the community after 3 years of restoration. However, 25-year restoration site had similarity index of only 56% with the natural marsh. Restored sites had higher species richness and diversity than the cropland and the natural marsh, indicated that environmental conditions of these sites facilitating more species (both upland and wetland species) development. The species diversity became more similar to the natural marsh with the time extension of restoration. We also found plant biomass can restored easier than the species composition and diversity in restored sites. Our results indicate that plant species composition and diversity of abandoned reclaimed wetlands can restored gradually by natural succession method in Sanjiang Plain. However, two decades are not enough for complete restoration of vegetation.

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