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# The soil seed banks of typical communities in wetlands converted from farmlands by different restoration methods in Nansi Lake, China

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ABSTRACT

Converting farmlands into wetlands is a widely used restoration engineering technique in China. To elucidate the ecological succession in restored wetlands, the background characteristics and the effects of the restoration method on seed banks should be analyzed. On the basis of seedling emergence method, we examined the seed banks of typical plant communities in wetlands that were converted from farmlands from the mouth of the Xinxue River to the Nansi Lake in China. The effects of the restoration methods on the seed banks of the typical communities were analyzed over three seasons. Results show that 43 species exist in the germinable seed banks of the wetlands converted from farmlands in the Nansi Lake area. The average seed density is 2822 seed/m$^2$ (0 –12,499 seed/m$^2$), and some species have persistent seed banks. Species abundance and seed density vary among different communities. The *Populus nigra* community has the most abundant species in the seed bank, followed by the *Phragmites australis*, *Potamogeton crispus*, and *Nelumbo nucifera* communities. The restoration method, season, community type, and their interaction are found to exert varying effects on the characteristics of the seed bank. Findings suggest the presence of a particular quantity of seed reserves in the seed banks of the wetlands; i.e., certain species with persistent seed banks can be used to restore wetland vegetation. Restoration methods significantly influence different seed banks. The restoration mechanism might be attributed to the differences in seed resource and seed loss. The diverse strategies of propagation by various species and the emerging characteristics lead to the differences among the seed banks of different communities and the seed banks in different seasons. Thus, the effects of the restoration method on the soil seed banks in the restoration of wetland vegetation need further investigation.



## 1. Introduction

Wetlands have a significant function in maintaining the stability of the global environment (An et al., 2007). However, approximately 50% of global wetlands have been lost since the 1900s mainly because of agricultural development (Jarrod et al., 2010). The wetland ecosystem in China was considerably destroyed by the development of aquaculture on surrounding lakes (Zhao and Gao, 2005; Sheng et al., 2011). Thus, the Converting Farmland to Wetland Project has recently been promoted in the main lakes of China for wetland restoration (Huang et al., 2009; Yan et al., 2010). Nansi Lake is one of the earliest demonstration sites selected (Liu et al., 2011).

The soil seed bank is one of the key components affecting the resilience of ecosystems. The soil seed bank is closely related to historical vegetation (Xiao et al., 2010), current vegetation (Capers, 2003; Liu et al., 2005; Hopfensperger, 2007), and future vegetation (Gurnell et al., 2006). Soil seed banks are used in wetland vegetation restoration (McKinstry and Anderson, 2003; Nishihiro et al., 2006; Li et al., 2008; Klimkowsk et al., 2010; Hong et al., 2012) and as an index of the efficiency of restoration engineering (Neff et al., 2009). It is also recognized as an important reference in formulating restoration strategies (Lu et al., 2012). Given the vital functions of the soil seed bank in wetland vegetation restoration, research on the wetland seed bank has recently drawn an increasing interest (Li et al., 2009). Numerous studies examined the factors that potentially affect the characteristics of the soil seed bank. These factors include environmental factors (Grelsson and Nilsson, 1991; Peterson and Baldwin, 2004; Neff and Baldwin, 2005; Liu et al., 2009), anthropogenic factors (Lavorel et al., 1993; Martins and

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Engel, 2007; Daïnou et al., 2011), varying seasons (Miao and Zou, 2009), stage of vegetation succession (Figueroa et al., 2004), and others (Li et al., 2012). The restoration method is also among the most important factors affecting the species composition and seed density of the soil seed bank in wetlands (Galatowitsch and van der Valk, 1996; Campbell et al., 2002). Thus, studies on the soil seed bank are crucial in understanding vegetation restoration (Daïnou et al., 2011; Rivera et al., 2012; Wang et al., 2013b).

The soil seed bank should be maximized in the restoration of the wetland vegetation (González-Alday et al., 2009). Thus, the characteristics of the seed bank and the factors influencing them must be thoroughly understood before the targeted restoration strategy is formulated. The present study on the effects of restoration engineering on the soil seed banks of wetlands converted from farmlands provides a theoretical reference for determining the pattern of restoration, selecting the species or species group for restoration, and evaluating the effectiveness of restoration methods. Seed banks in numerous ecosystems have been extensively examined; however, seed banks in wetlands converted from farmlands have rarely been studied. The characteristics and variation principles of seed banks in wetlands converted from farmlands after restoration engineering remain undetermined.

Located in North China, Nansi Lake is one of the largest inland freshwater lakes in the east route of the National South-to-North Water Transfer Project. Thus, the wetland ecosystem functions of Nansi Lake are vital to the water quality security of the project (Liu et al., 2011). Occupying an area of 7000 $hm^2$, wetlands converted from farmlands are among the earliest demonstration sites for the Converting Farmland to Wetland Program. The area includes wetlands with and without the application of restoration engineering, which refers to artificial methods such as topographical reform, hydrology restoration, targeted wetland species planting, and management to the restoration of wetland. These conditions facilitate the study of the effects of restoration method on the soil seed banks of wetlands converted from farmlands. We studied the effect of restoration method on the soil seed banks of different communities in different seasons. The results show potential in elucidating the effects of the restoration method on vegetation in the wetlands converted from farmlands. The findings also provide a scientific guide for wetland restoration practices.

## 2. Methods

### 2.1. Site selection

Nansi Lake is located in Shandong Province, China (116°34′ to 117°21′ E, 34°27′ to 35°20′ N). The lake has a total water area of 1266 $km^2$ and an average water depth of 1.5 m. The climate is sub-humid warm temperate continental monsoon. The annual average temperature is 13.7 °C, the annual average sunshine is about 2530 h, and the frostless period ranges from 209 days to 224 days. The annual average precipitation is 700 mm, and about 60% of precipitation occurs in summer. The surface of the lake freezes usually from mid December to next early February.

Two wetlands converted from farmlands by different restoration methods were selected based on our field investigation of the wetlands in the entire Nansi Lake area (Ge et al., 2012). One wetland was converted from farmland by restoration engineering, located at the mouth of the Xinxue River; the other wetland was also converted from farmland only by stopping the tillage. The two wetlands are separated by the Xinxue Dam (Fig. 1). The two sites, which had been used as farmlands before 2005, have similar topography, hydrology, and vegetation cover. Both sites had also been subjected to similar human disturbances prior to wetland restoration. The wetland converted from farmlands by restoration engineering has been used as a surface flow wetland planted with aquatic plants (*Arundo donaxl*, *Phragmites austrilis*, *Nelumbo nucifera*, and others) to remove nutrients from the Xinxue River (Zhang et al., 2008), thereby increasing the water level and the flow rate. Humans oversee the protection and management of the wetlands, including targeted wetland species planting (mainly referring to reed and lotus), regular harvesting, and control of water inflow. The other site, which is a nearly natural recovering wetland from farmlands without restoration engineering, was subjected to constant human disturbances such as grazing, fishing, and inorganized harvesting. In addition, the inflow rate of the latter site is less than that of the former site.

### 2.2. Sampling method

Four typical communities from the two sites were selected: *Populus nigra* community (in water-saturated land), *Phragmites australis* community (in seasonally flooded land), *N. nucifera* community (in shallowly flooded land), and *Potamogeton crispus* community (deeply flooded). The habitats of these communities are commonly characterized by the level of water supply: saturated, seasonally flooded (about 0–50 cm), shallowly flooded (about 50–150 cm), and deeply flooded (120–300 cm). We randomly constructed three sample plots for each of the eight communities.

Soil samples were collected in August and December 2009 and March 2010. Thirty soil cores that were 3.0 cm in diameter and 12 cm deep each were randomly collected from each plot and mixed to form a soil seed bank sample. A total of 72 soil seed bank samples were washed using a fine sieve (80 mesh per inch) to eliminate clay and silt. Distinct roots and gravel were manually removed. Concentrated samples were sealed separately into valve bags and stored in darkness at a temperature ranging from 4 °C to 5 °C until the germination test, which was conducted on April 15, 2010.

### 2.3. Seedling emergence method

Each concentrated soil sample was weighed and divided into three subsamples. One subsample was tiled in a plastic rectangular pan (20 cm × 11 cm × 5 cm) on the surface of a 3 cm thick layer of pond soil. The pond soil was obtained from the Xinxue River wetland and had been sterilized (at 105 °C for 24 h) in a drying oven to remove the viable seeds. All subsamples had a layer thickness of not more than 0.5 cm. All pans were placed in a laboratory lit by plant cultivation lamps for 10 h per day. Light intensity ranged from 1320 Lx to 2190 Lx at daytime, temperature varied from 15 °C to 30 °C, and humidity ranged from 60% to 90%. The substrate remained saturated using tap water supplement.

### 2.4. Seedling enumeration

The samples were monitored once a week for seedling emergence. The species taxa and the number of seedlings that emerged successively in each pan were recorded. The seedlings were either recorded and pulled after identification or transplanted and cultivated to maturity for taxonomic identification. The germination experiment was completed in February 2011.

### 2.5. Data analysis

The seedlings and the species that emerged in each pan were allowed to accumulate to calculate the seed density and the species abundance of the seed bank (Ter Heerdt et al., 1996). To identify the general status of the seed banks of wetlands converted from