



Characteristics of the soil seed bank of planted and natural restored draw-down zones in the Three Gorges Reservoir Region



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ABSTRACT

The large-scale reverse seasonal water-level fluctuation caused by the Three Gorges Reservoir Project has dramatically changed the ecology of draw-down zones leading to degradation of local riparian vegetation. We studied the Wanzhou draw-down zones in the Three Gorges Reservoir Region via field investigations and soil seed bank (SSB) germination experiments. The composition and spatial distribution of the SSB in the planted and natural restored sites revealed the effects of restoration modes on seed bank development and demonstrated responses of SSB composition and structure to water fluctuation. The SSB of planted sites contained 43 species of plants, with a mean seed bank density of 9418.79 seeds/m², where annual herb species accounted for 57.34%. The SSB at natural restored sites had 38 species of plants, with a mean seed bank density of 6090.09 seeds/m², where annual herb species accounted for 52.57% of the species. Species diversity was low and annual plants dominated the two restoration sites. SSB species diversity was the highest in mid to upper levels of the draw-down zones. Plantation has increased co-occurrence species of SSB and standing vegetation, and increased their similarity. The number of co-occurrence dominant species of SSB and standing vegetation in planted areas was greater than in natural restored areas. However, the stability of plant communities naturally restored was greater than artificial plant communities as there was a higher proportion of perennials in the SSB with more dominant species similar to standing plant communities. In conclusion, the reverse water-level fluctuation simplified the species composition and shaped the spatial distribution of the SSB at the two restoration sites, and plantation promotes the development both of SSB and vegetation. However, plant communities of the two restoration areas, influenced by water-level fluctuations, will be mainly grasslands dominated by annual plants.

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1. Introduction

Soil seed bank (SSB), and its relationship with standing vegetation, plays an important role in plant community succession (Liu et al., 2009; Kettenring and Galatowitsch, 2011). Composition of SSB and its relationship with standing vegetation are critical factors determining the dynamic of plant community (Wang et al., 2010; Liu et al., 2014). Species composition and spatial structure of the

standing vegetation, status of plant growth and propagation, and seed dispersal directly affect the composition and spatial distribution of the SSB (Wang and Zhu, 2002; Yuan et al., 2007; O'Donnell et al., 2016). Composition and structure of the SSB help to examine the structure and function of standing plant communities (Leck, 2003; Liu et al., 2006a). In areas with frequent serious disturbances the effect of SSB on vegetation would be of great significance (Yu and Jiang, 2003; Landman et al., 2007). Vegetation restoration process has a great influence on the development of the SSB (Moore et al., 1999). Plantation can be effective in restoration of vegetation and SSB, but the restored ecosystems often lack stability and sustainability due to the introduction of non-native species (Liu et al., 2006a; Nishihiro et al., 2006). Natural recovery process is slow, but the species composition and structure of the final plant community

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and soil seed bank are more similar to surrounding vegetation and this often results in higher stability and sustainability (Landman et al., 2007; Wang et al., 2011a). Study of SSB recovery characteristics and their relationship with vegetation restoration can help us understand the role of restoration process on SSB development and distribution (Wang et al., 2013).

Draw-down zones are areas adjacent to rivers, lakes, and reservoirs that are periodically submerged and exposed by water-level changes. After the completion of the Three Gorges Project, draw-down zones with vertical fluctuation ranges of 30 m and a total coverage of 450 km² were formed. These are characterized by a reverse water-level fluctuation pattern, air exposure in summer and submersion in winter (Wang et al., 2010; Chen and Xie, 2009). The large scale and reverse seasonal water-level fluctuation has altered the ecology of draw-down zones. Many of the plants were not adapted to the new environment, and disappeared. Composition and structure of the new plant community tends to be simple (Wang et al., 2011b; Lei et al., 2014; Lu et al., 2010a). Following completion of the Three Gorges project, several research and demonstration projects were launched to cope with ecological restoration issues of the degraded draw-down zones. Field investigation indicated these projects promoted the restoration of riparian plant communities (Chen et al., 2016; Tang et al., 2012). We hypothesize that plantation also promote development of soil seed banks. We established experimental sites on the planted and natural restored riverbanks in Wanzhou in the Three Gorges Reservoir region. Species composition and spatial distribution of SSB and similarity between SSB and standing plant community on the planted and natural restored sites were studied respectively. The objectives of our research were (1) to quantify the difference in composition and seed density of SSB between the planted and natural restored sites to evaluate the effects of plantation on the development of SSB; (2) to investigate the variation in composition and seed density of SSB along altitude gradients to uncover the effects of the reverse seasonal water-level fluctuation on spatial distribution of the SSB in the draw-down zones. Ultimately, the research will help forecast the future plant community in the draw-down zones due to the completion of the Three Gorges Project.

2. Study method

2.1. Study area

The study area is located in Xintian Town, Wanzhou District, Chongqing City, China, dominated by subtropical monsoon climate. Annual mean temperature is 17.7 °C, mean annual rainfall is about 1067 mm, and relative humidity ranges from 79% to 92%. The experiment area has a 28° slope. Soil type is yellow limestone, and soil layer thickness is about 35 cm.

A planted draw-down zone (30°43'33" N, 108°25'43.47" E) and a natural restored draw-down zone (30°43'33" N, 108°25'43.46" E) were established. The plantation project was completed in 2008 and the recovered area was about 15000 m². Seeds of Bermuda grass (*Cynodon dactylon*) were sowed below altitude 160 m; *Acorus gramineus* were planted at altitudes 160–170 m; and for altitudes 170–175 m, trees such as *Morus alba*, *Salix babylonica* and *Sophora japonica* and shrubs such as *Rhus chinensis*, *Zanthoxylum bungeanum*, and *Vitex negundo* were planted, and seeds of *C. dactylon* were sowed. After six cycles of water-level fluctuation, relatively few trees and shrubs survived at altitudes 170–175 m. Some willows (*Salix babylonica*) survived. Grassland, with *Setaria* and *C. dactylon* as dominant species, was formed at altitudes 145–170 m. Grassland, with *Polygonum hydropiper* and *C. dactylon* as dominant species, was formed at altitudes 170–175 m. The natural restored areas had no artificial disturbances and were maintained in a

natural state of recovery. In the natural restored areas, grassland, with *Alternanthera philoxeroides* and *C. dactylon* as dominant species, formed at altitudes ranging from 145 to 170 m. Grassland, with *Bidens frondosa* and *C. dactylon* as the dominant species, formed at altitudes ranging from 170 to 175 m.

2.2. Quadrat setting and sampling

A total of 6 transects were established at intervals of 5 m from altitudes 150–175 m in both of the planted and natural restored sites, and a total of 25 quadrats covering 1 × 1 m² each were included in each transect. Sample sites were marked and samples of soil seed bank were collected from quadrat with exposure of land at different altitudes during March to April. Surface vegetation and leaves were removed then SSB samples were collected using an 8 cm wide by 15 cm long soil sampler. Soil samples were put into a self-sealing bag. A total of 150 soil samples were collected from each restoration site. The soil samples were used for laboratory seed germination experiments.

Vegetation investigation was carried out for above-mentioned areas during August. Grassland was inventoried using 1 × 1 m² quadrats, so did shrub-land using 5 × 5 m² quadrats. Plant species, and plant quantity and average height of each species were record. Species coverage was evaluated by the grid visual method.

2.3. Germination experiment of SSB

Soil samples were air dried, crushed, and stones and impurities were removed using a 4 mm sieve. Sieved soil samples were layered on germination plates (20 cm × 15 cm × 5 cm) with 3 cm of sterilized dry sand as base material. The thickness of soil was less than 2 cm. The dried sand in the germination plate was previously heated at 120 °C for 12 h to ensure that any seeds contained were deactivated. The germination plates were randomly placed in an artificial climate box and cultured at 25 °C, 24000 lx illumination, and 60% RH. Sufficient water was given to keep the soil moist. Seedlings emerging from the soil were identified. We recorded the species and number of seedlings and then removed them from the plates. Seedlings not readily identifiable were transplanted into single pots and grown until identification was possible. We recorded plant species, and the life-form and seed number of each species germinating in each soil sample.

2.4. Data analysis

Each soil sample was considered as a replicate. The characteristics of species and life-form composition of the SSB in different restoration sites were analyzed. The importance values of different plant species in the SSB of planted and natural restored sites and the different elevation gradients were calculated respectively (importance value of species = relative density + relative coverage + relative frequency). Simpson dominance index, Shannon-Wiener diversity index, and Pielou evenness index of each SSB were calculated to analyze characteristics of species diversity of the planted and natural restored sites and responses to water-level fluctuation. With the altitude gradient as the independent variable, and seed density as the dependent variable, one-way ANOVA was used to analyze quantitative characteristics of the SSB at different altitudes. When the single factor effect was significant, an LSD test was performed to compare differences among the groups. This evaluated the composition and spatial distribution characteristics of SSB under different restoration modes. The data analysis was carried out using SPSS 17 package for Windows (SPSS, Chicago, IL, USA).

The importance values of each species in plant communities in the planted and natural restored sites and the different

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