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Short communication

Revegetation in the water level fluctuation zone of a reservoir: An ideal measure to reduce the input of nutrients and sediment

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ABSTRACT

The Three Gorges Dam (TGD) is one of the largest dams in the world. Due to the management of the Three Gorges Reservoir (TGR), a huge water level fluctuation (WLF) zone was formed and this caused significant changes to the vegetation in this area. A local vegetation survey was conducted in the WLF zone of the Xiangxi River, one of the major tributaries of the Three Gorges Reservoir, from 2010 to 2011. Based on the survey results, a revegetation method using *Cynodon dactylon* was established. *C. dactylon* can survive after very long periods of submergence, and using local species to restore vegetation can prevent the introduction of invasive species. After long-term growth and propagation, the vegetation in our experimental plots was restored, resulting in beneficial landscape and ecology effects. According to our in situ experiments, revegetation in the WLF zone significantly reduced the flow of nutrients and sediments into the TGR. Furthermore, the *C. dactylon* plots produced less biomass than did the control plots, meaning that less organic matter was introduced to the water. In conclusion, *C. dactylon* is a suitable candidate for use in the revegetation of the WLF zone of the TGR, and revegetation of the WLF zone will be beneficial in the maintenance of water quality of the TGR.

1. Introduction

Many dams have been built around the world to meet the growing demands for both clean energy and irrigation water, and this phenomenon has intensified dramatically in the last century (Mallik and Richardson, 2009). The Three Gorges Dam (TGD) which is located in central China is one of the largest water projects ever built. After the impoundment of the dam, a huge reservoir formed. This is known as the Three Gorges Reservoir (TGR) (Peng et al., 2013). Due to the management of the TGR, an artificial water level fluctuation (WLF) zone with a maximum upright fall of 30 m and an area of more than 300 km^2 (Wang et al., 2009; Ma et al., 2012) is formed annually in the TGR area. However, the timing of the fluctuation is opposite to the natural inundation regime (Subklew et al., 2010). This shift has brought about a significant change in the habitats for vegetation in the WLF zone. Research has shown that the composition of plant species in the WLF zone is significantly different from the surrounding natural areas. The dominant species in the WLF zone are graminoids, annual and perennial forbs (Lu et al., 2010a,b), such as *Xanthium sibiricum*, *Alternanthera philoxeroides*, *Bidens pilosa*, *Cynodon dactylon* and *Setaria viridis*.

In the winter, the water level of the TGR reaches its maximum height of 175 m above sea level, this period lasts more than six months of the year (Su et al., 2012). The vegetation in the WLF zone is submerged in the water at this time, and all of the aboveground parts of the vegetation (shrubs, forbs, etc.) die during the submergence period (Wagner and Falter, 2002). This die off introduces a lot of organic matter into the water of the reservoir. Rainfall is a major element of the hydrologic cycle, and it is responsible for depositing most of the fresh water on land (Barua et al., 2013). The freshwater ecosystems in China are directly influenced by the Asian monsoon during the summer, and concentrated rainfall is known to play a key role in determining water quality (Brewin et al., 2000). The vegetation on the surface of the ground helps reduce soil erosion and helps to intercept the movement of sediment (Wu and Hua, 2014). During the rainy period, new sediment is deposited on the vegetation of the riverside. The alteration in plant species composition can often lead to increased soil erosion. Much attention has been

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focused on the succession, restoration, and reconstruction a plant communities in WLF zones (Wu et al., 2003; Plateau, 2006; Mitsch et al., 2008).

Cynodon dactylon, a perennial, is one of the most common plant species found in the WLF zone of the TGR area (Liao et al., 2010). More than 90% of *C. dactylon* plants remain viable after 180 days submergence (Wang et al., 2008), and only the leaves decay during submergence. *C. dactylon* plants can recover quickly during the following spring, and these plants have deep root system. Most of the root mass is less than 60 cm under the surface of the soil. The grass creeps along the ground and roots wherever a node touches the ground, forming a dense mat. *C. dactylon* reproduces via seeds, runners, and rhizomes.

A method of rapidly establishing the vegetation in the WLF zone of reservoirs was established in this study. The effects of the recovered vegetation on nutrient and sediment inputs were analyzed.

2. Materials and methods

2.1. Study area description

The Xiangxi River is located in the western part of Hubei Province, China (30°57′N–31°34′N and 110°25′E–111°06′E). It has a primary course that is 94 km long, and a watershed of 3099 km^2 (Peng et al., 2013). After the impoundment of the TGD, a new WLF zone with a maximum upright fall of 30 m was formed in the watershed of the Xiangxi River, and the composition of plants in this area was changed significantly. Woody plants and shrubs have almost disappeared in the WLF zone; annuals and perennial forbs now dominate in this area during low water level periods. Revegetation experiments were conducted at site *R* (Figure S1 of the Supplementary Material). The vegetation recovery experiments were performed with three replicates. The areas in which the experimental plots were located contained large amounts of mud and gravel. The soil was tilled slightly prior to commencing the experiments.

2.2. Vegetation recovery

2.2.1. Plant materials and treatments

C. dactylon is a perennial herb in the family Gramineae, and grows widely in the TGR area. *C. dactylon* rhizomes were collected from the WLF zone of the TGR, cut into pieces of 5–8 cm in length, and sown in the three experimental plots. Mesh fabric was used to cover the plots; plots were watered 2–3 times per week. Three plots without sowing were used as controls; these were watered at the same time as the sown plots. The sowing rate of *C. dactylon* rhizomes was 1.6 kg m^{-2} (fresh weight).

2.2.2. Measurements

The vegetation coverage was assessed visually within $0.25 \times 0.25\ m^2$ plots (Zhao et al., 2011) at 30, 60, 90, and 120 days after sowing. The accumulated biomass of vegetation was measured by weighing the collected aerial parts of the vegetation, which were collected from $1 \times 1\ m^2$ plots. Simulated precipitation was conducted for the plots with an area of $1 \times 1\ m^2$; the amount of precipitation was 24 mm, and the run-off water was collected. Water samples were taken to a field laboratory and analyzed within 4 hours. Sediments were collected by centrifugation at 3000 rpm, and then dried at 105 °C until the masses stopped declining (i.e. dried to constant weight). The total dissolved nitrogen (TDN) and total dissolved phosphorus (TDP) concentrations in the collected water were measured according to standard methods for the examination of water and wastewater (APHA, 1995).

2.2.3. Statistical analysis

Differences between the revegetation experiments and the control groups were evaluated using Student's *t*-tests. Statistical analysis was conducted using SPSS 20.0 (SPSS Inc., Chicago, USA).

3. Results

3.1. The structure of vegetation

A total of 23 and 21 plant species were identified in the 2010 and 2011 surveys (Table S1 of the Supplementary Material). Annual and perennial forbs dominated in the WLF zone during the investigation. There were more annual forbs than perennial forbs, and almost no shrubs were found. There was no significant difference in the structure of vegetation at the same sites between 2010 and 2011 (Table S1 of the Supplementary Material); this indicates that the structure of vegetation in the same location of the WLF zone was stable and changed little year to year. The revegetation experiments were conducted in plots that did not have any *C. dactylon* plants growing before the trials. There were no *C. dactylon* plants found in the control plots following the experiments; this is likely due to the difficulty of bearing seeds in the period prior to submergence. At the start of the revegetation experiments, there were many annual forbs found in the experimental plots planted with the rhizomes of *C. dactylon*; the proportion of forbs in the plots ranged from 5% to 8%. Notably, *C. dactylon* plants recovered quickly and the annual forbs thus lost their advantage for growth. By the end of the experiment, the proportion of forbs had decreased to the range of 1.2–2.5%. The dominant species in the control plots were *S. viridi*, *X. sibiricum* and *B. pilosa*.

3.2. Vegetation coverage

There was no significant difference in coverage between the *C. dactylon* and control plots; the coverage was nearly 90% for both plot types at the end of the experiment (Fig. 1). *C. dactylon* has more rhizomes, these are able to stabilize soils better than other species in the control plots.

3.3. Biomass accumulation

The accumulated biomass of the plants increased during the time course of study, and the results showed that the amount of

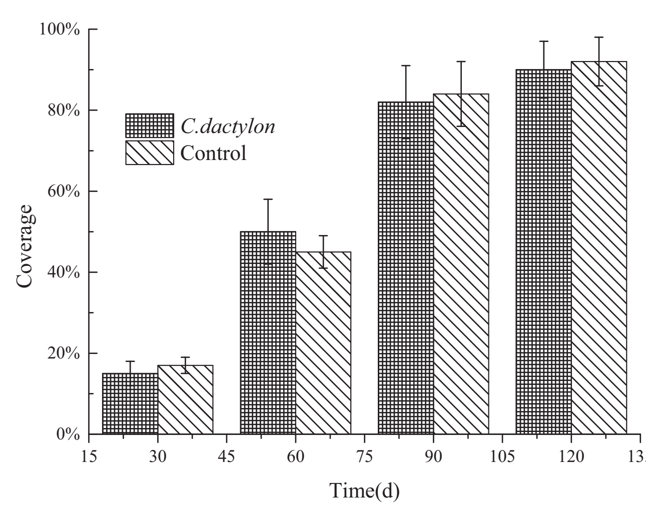

Fig. 1. The vegetation coverage (%) of the *Cynodon dactylon* and control plots during the study period.