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Seed banks of a river–reservoir wetland system and their implications for vegetation development

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ABSTRACT

The Danjiangkou Reservoir, constructed in 1970s, is the water source area of the middle route of China's interbasin South-to-North Water Transfer Project. To serve such purpose, the Danjiangkou Reservoir Dam will be increased from its present 162.0 m to 176.6 m, and its regular water level from 157 m to 170 m above mean sea level. Vegetation development in the new reservoir margins is therefore one of great environmental concerns. To explore the potential origin of species in the present reservoir margin vegetation, we investigated and quantified the composition in the soil seed banks and established vegetations of the reservoir margins and its upstream- and downstream-wetlands. In both existent vegetation and seed banks, most species and seedlings were found in upstream wetlands, followed by reservoir margins and downstream wetlands. Seedling density of downstream wetlands was reduced by 75–80% compared to upstream wetlands and reservoir margins. This suggests that presence of the dam reduced the diversity and abundance of downstream propagules. Sørensen's coefficient and the comparisons of rare species indicated that the seed bank composition of reservoir margins was evidently associated with upstream wetlands. It implies that hydrochorous transport of seeds from the upstream catchment is critical for plant colonization of the reservoir margins.

1. Introduction

Although more than 22,000 large dams have been (or are being) established in China in the past century, their ecological and environmental implications have received limited attention from the Chinese scientific community (Wu et al., 2003, 2004; Zhang, 2005). A dam and its associated environmental alterations may result in a number of regional changes in biodiversity, as well as ecosystem structure and functioning (Wu et al., 2004). Trajectories of reservoir margin vegetation responding to seasonal exposure and immersion influence higher-order responses such as wildlife habitats and biogeochemical processes. Restoration of reservoir margin vegetation is therefore important.

A bottleneck for restoration can be the re-establishment of local and regional species pools (Zobel et al., 1998) which is also affected by characteristics of plant reproduction such as propagule dispersal, soil seed banks, germination and establishment (Geertsema et al., 2002). Propagule dispersal can allow colonization of widely dispersed restoration sites from spatially remote, remnant target species populations. Dispersal efficiency mainly depends on the availability and efficiency of dispersal vectors. For the restoration of reservoir margin vegetation flowing water appears to be one of the most efficient natural dispersal vectors (Schneider and Sharitz, 1988; Johansson and Nilsson, 1993; Jansson et al., 2005), and hence may play an important role in plant community establishment and species richness maintenance.

The soil seed bank may be a useful indicator of the likelihood of success in restoring vegetation communities (Grillas et al., 1993; Bonis et al., 1995; Middleton, 2003; Liu et al., 2006; Nishihiro et al., 2006). In a hydrologically connected river–reservoir system (*i.e.*, reservoir and its upstream, downstream rivers), the riparian seed bank reflects interactions between hydrological, geomorphological and ecological processes.

In this paper, we compared the species composition of the seed banks and the established vegetations of the reservoir margins with those in the upstream- and downstream-riparian wetlands of the Danjiangkou Reservoir. The objectives of our study were (1) to investigate variation in composition of seed banks and the vegetation of the river–reservoir system, (2) to quantify the difference in composition of vegetation and seed bank between reservoir margins, upstream- and downstream-wetlands, and (3) to explore the origin of species in the present

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reservoir margin vegetations and seed banks. Ultimately, the research will help forecast the future reservoir margin vegetation due to the implementation of the interbasin water transfer project.

2. Methods

2.1. Study area

The Danjiangkou Reservoir (32°36′–33°48′N, 110°59′–111°49′E), with a water surface area of 745 km^2, is located at the juncture of the Hubei and Henan provinces (Fig. 1). The climate is subtropical with a mean air temperature of 2.4 °C in January and 28.4 °C in July. Mean annual rainfall is approximately 804 mm, and 80% of the total rainfall is concentrated between May and October. Over 85% of the reservoir margin is mountainous. The vegetation is composed of coniferous (e.g., *Pinus massoniana*, *Cunninghamia lanceolata*), and broad-leaved mixed forest, shrub and herb, and the forest cover is approximately 35% (Shen et al., 2006). A lower water level is maintained in spring and summer compared to autumn and winter, leading to an emergent and relatively dry reservoir margin during the plant growth season.

The Danjiangkou Reservoir Dam, located in the Han River, was constructed in the 1970s. In 2002, the Chinese government launched a gigantic project, the three-route South-to-North Water Transfer (SNWT) Project to channel 44.8 billion $m^3\ y^{-1}$ of water from the Yangtze River and its tributaries to the drought-stricken North (Zhang, 2005). The Danjiangkou Reservoir is the water source of the project's middle route. Accordingly, the Danjiangkou Reservoir Dam will be increased from its present 162 m to 176.6 m, and its regular water level from 157 m to 170 m above mean sea level. Thus, a new area of approximately 370 km^2 will be inundated from the current hillsides between 150 m and 170 m.

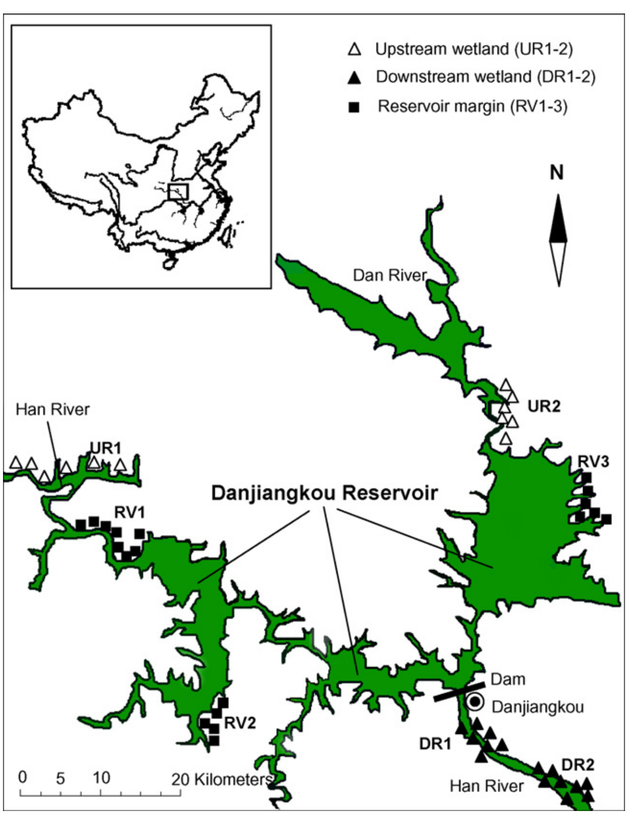

Fig. 1. Location of the sampling sites in the Danjiangkou Reservoir, China.

Seven sites were selected to represent a hydrologically connected river–reservoir wetland system, including upstream riparian, reservoir margin and downstream riparian wetlands. Two sites representing upstream wetlands were located at the reservoir entrance of the Han River and the Dan River, respectively. Three sites were selected along reservoir margins of two major water bodies of the Danjiangkou Reservoir, and two sites in downstream wetlands were located at the outlet of the reservoir (Fig. 1). Sites were chosen to represent typical communities and environmental conditions found in the above habitats. The site sizes varied between about 5 ha and 10 ha, and distances between sites range from 5 km to 40 km.

2.2. Standing vegetation survey

Species composition of vascular plants in standing vegetation was sampled in August 2004. At each site, five to eight (depending on site size) plots (six and six in upstream riparian; five, six and eight in reservoir margins; seven and eight in downstream riparian) were set at approximately 50 m intervals. A total of 46 plots were used for the three habitats (12 in upstream riparian, 19 in reservoir margins and 15 in downstream riparian). Each plot was 20 m length parallel with water's edge, and covering the entire width of drawdown area. Species were recorded within the plot whilst walking through the entire plot. Species cover was visually estimated using a scale of five classes: I $<$ 1%, II = 1–5%, III = 5.1–10%, IV = 10.1–20% and V $>$ 20%.

2.3. Seed bank analysis

The soil seed banks were sampled on the same plots as the vegetation survey in March 2004. At each plot, five soil cores of 10 cm depth were randomly taken after thoroughly removing the plant materials from the soil surface. Thus, soil cores were taken to represent the range of standing vegetation and subhabitats present. A steel soil corer was used (8.7 cm diameter), resulting in a sampling surface area of 297 cm^2 (volume 2970 cm^3) per plot.

Methods for recording seedling emergence followed van der Valk and Davis (1978). Five soil cores from the same plot were mixed homogeneous and visible roots, rhizomes, tubers and litter were removed after washing the soil. Each sample was wet-sieved (0.2 mm) and the retained material spread in a layer ($<$1 cm deep) on 3 cm of sand in a tray of 40 cm × 20 cm × 8 cm in size. The sand had previously been dried for 24 h at 75 °C to eliminate any weed propagules. Trays were watered once a day and monitored in an unheated greenhouse at Wuhan Botanical Garden. Seedlings were removed as soon as they could be identified, or transplanted into flowerpots until identification is possible. Seedlings numbers were recorded once a week until there had been no further germination for 1 month.

2.4. Statistical analysis

All species in above-ground vegetation and seed bank were classified as mud-flat, emergent species and submerged species according to their dominant growth form. The frequency of occurrence of individual species (*i.e.*, number of sites with species present divided by the total number of sites sampled) was compared between upstream riparian, reservoir margin and downstream riparian using chi-squared tests. To avoid type I error, a Bonferroni correction ($P = 0.05/3 = 0.017$) was used to determine differences in statistical significance.

Sørensen's coefficient of similarity was used to compare species composition among the three habitats. Since there were a large number of occurrences of rare species, the actual similarity in a