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A field study on seed bank and its potential applications in vegetation restoration of a polluted urban river in China

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ABSTRACT

As an important component of restorations of polluted and/or degraded rivers, vegetation recovery has become a research highlight in the last two decades. Seed bank have been used as the best tool to allow natural recolonization of indigenous plants probably occurring before the degradation of the water bodies. To illustrate the relationship between water pollution and distribution of seed bank and evaluate the potential application of seed bank in vegetation restoration of polluted rivers, an urban river, Nanfeihe River was selected as the investigation target. A total of 27 species from 17 families with dominant families of Poaceae (5 species) and Polygonaceae (4 species) were identified in 38 channel bed samples. The observed species included 4 aquatic, 7 wetland and 16 terrestrial species, which occupied 15%, 26% and 59% of the total species, respectively. The species richness at the 10 sampling sites varied from 7 to 19, and the seed densities varied from 804 to 1.48×10^4 seedlings m^{-2}. Species richness and seed density in the river margin were significantly higher than those in the mid-channel ($P < 0.05$), and those in upper sediment layers were also higher than those in sub-layers. The species richness and Shannon Index of seed bank were significantly related to total nitrogen (TN) concentration in the sediment by Gauss regression ($R^2 = 0.94$, $P < 0.001$ and $R^2 = 0.91$, $P < 0.001$). Increasing TN concentrations in sediment eventually led to the decline of species richness and diversity. CCA ordination suggested that water depth and NH_4^+–N concentration in water column played an important role in shaping the pattern of seed bank in the river. Perhaps water pollution not only caused degradation or even disappearance of standing vegetations, but also influenced the storage and distribution of seed bank. In addition, nitrogen-loading gradient along the river was probably capable of determining the pattern of seed bank at certain extend. The quantitative relations between the pattern of seed bank and water pollution give us insight to evaluate the potential application of seed bank in vegetation recovery in polluted urban rivers, and it would also contribute to urban riverine management, diversity conservation and ecological assessment.

1. Introduction

Rivers provide various ecological functions, such as water supply, biodiversity conservation, landscape and so on, and their natural, social, economic and environmental values in the modern cities are irreplaceable. Unfortunately, nowadays most of the river ecosystems, especially in the cities, have extremely degraded due to some anthropogenic disturbances such as sewage loading, non-point source pollution, dam construction and channelization, destroy of riparian vegetation and the introduction of invasive exotic species (Girel and Manneville, 1998; Hering et al., 2006; Kondolf et al., 2006). River or stream restoration has been an important environmental issue for the past decades in the world (Nakamura et al., 2006; Søndergaard and Jeppesen, 2007). Most of the restoration projects include activities to recover the lost or degraded vegetation and plant diversity (Nishihiro et al., 2006b). The best method, if it is possible, is to allow natural colonization with propagules and/or seeds remaining in the river bed or from upstream reach (Haslam, 1996). The usage of soil seed banks is becoming a common revegetation technique because of its advantages in conserving and restoring biodiversity (Goodson et al., 2001; Matus et al., 2003; Nishihiro et al., 2006a).

The seed bank is an useful indication of the potential species composition at a site (Liu et al., 2006; Nishihiro et al., 2006b). Knowing the seed bank composition and distribution can contribute to the historical and predictive understanding of plant community composition (van der Valk, 1981; Cavers, 1995), determining probable species composition following a disturbance (Hölzel and Otte, 2004; Xiao et al., 2010) and predicting the potential contribution

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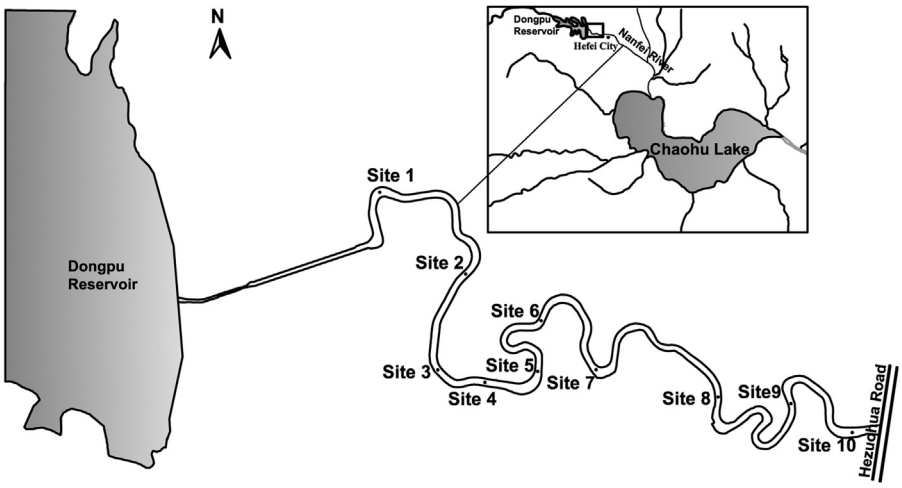

Fig. 1. Locations of 10 sampling sites.

of the seed bank for the restoration of a target plant community (McDonald et al., 1996; Lu et al., 2010). Many studies have highlighted the importance of soil seed bank in restoration of vegetation in degraded wetlands (Haslam, 1996; McDonald et al., 1996; Williams et al., 2008), and knowing the species available in the seed bank can be helpful to make decisions on the species need to be planted.

In the rivers, plant propagules are dispersed and deposited along the river corridor through a variety of natural mechanisms, including direct deposition from the parent plants and transport by wind, water and animals (Goodson et al., 2001; Boedeltje et al., 2003). Some reports verified that hydrochory plays a key role in transporting and depositing freshly-produced seeds along river corridors (Vogt et al., 2004; Jansson et al., 2005; Gurnell et al., 2006; Liu et al., 2009), and the river-bed might be the temporary storage of plant seeds (Gurnell et al., 2007).

The composition and distribution of seed bank in the river system are related to many factors. The traits of species, such as the buoyancy of seeds, the ability to release vegetative fragments and the frequency of occurrence in the established vegetation and so on, had been mentioned in structuring variation in propagule pool (Boedeltje et al., 2003). As to environmental factors, hydrology, nutrient status, sediment composition and hydraulic conditions in distributing and structuring plant propagules along the river system were recognized to be important (Nilsson et al., 1991; Merritt and Wohl, 2002; Gurnell et al., 2008). In recent years, increasing attentions were paid to the effects of human activities on the pattern of seed bank. For example, how did livestock grazing and land clearing (Amy and Robertson, 2001; Williams et al., 2008), channelizing and dam construction (Liu et al., 2009) influence the seed bank transaction in the river system. Although the seed bank of river bank and riparian area has received substantial attentions, the role of channel bed as a reservoir of viable seeds and propagules has been virtually ignored (Goodson et al., 2001; Gurnell et al., 2007; Williams et al., 2008). Some studies have indicated that storage of viable propagules within sediments deposited on the bed of river channels may be significant (Gurnell et al., 2007, 2008). Lots of information have been given on how seed bank distribution and composition vary among sediment properties and hydrological conditions (Nilsson et al., 1991; Hölzel and Otte, 2001; Goodson et al., 2002), little knowledge is available on effects of urban polluted river bed, and the role of discharge of domestic wastewater and subsequent water pollution, or water quality on the seeds deposition in the river bed is not well understood.

The previous studies had shown that the revegetation methodology, i.e., what species and how they should be introduced to the site, is important to successful restoration (Nishihiro et al., 2006a,b). If the target species are available in the sediment seed bank, revegetation could be achieved naturally by adjusting the environment of the site to an appropriate level. Therefore, preliminary research on the sediment seed bank and the effects of water pollution and restoration projects on its composition and distribution could provide a valuable but inexpensive resource for revegetation. In this study, the sediment seed bank along Nanfeihe River, a polluted urban river in China, was investigated to address: (1) the storage and distribution of the sediment seed bank affected by long-term pollution from domestic wastewater, non-point source pollution of surface runoff, and some restoration projects, etc., (2) the relationship between the sediment seed bank and the pollution level or anthropogenic disturbances, (3) the feasibility of using sediment seed bank for revegetation in the degraded urban river ecosystem and some implications for restoration measures.

2. Materials and methods

2.1. Study sites

The 70 km-long Nanfeihe River with 1464 km^2 catchment is a main tributary of Chaohu Lake, which is the fifth largest freshwater lake of China. It is a typical urban river, flows through Hefei City, Anhui Province, from the northwest to the southeast and is known as the “Mother River” of the city. It receives water mainly from the Dongpu Reservoir, tributaries Silihe River, Banqiaohe River, Ershibuhe River and Dianbuhe River, and effluent from wastewater treatment plants (WWTPs).

As a main recipient of pollutants from Hefei City, the water quality of Nanfeihe River is worse than Grade V according to the Chinese National Environmental Quality Standard for Surface Water (GB3838-2002). It becomes eutrophication and its ecosystem deteriorates. Most of the macrophytes and other aquatic organisms in the channel have disappeared, except some *Hydrocharis dubia* (Bl.) Backer and *Alternantera philoxeroides* (Mart.) Griseb. Recently, several restoration engineering projects with various scales and techniques had been implemented on the river, mainly by introducing fresh plants and/or mown materials. In the riparian zone, some ecological rehabilitation techniques were also applied to restore its ecological structure and function.