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Ecological effect assessment based on the DPSIR model of a polluted urban river during restoration: A case study of the Nanfei River, China

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ABSTRACT

Urban rivers play an important role in the sustainable development of cities. With increasing attention being given to the implementation of urban river restoration, a more integral and reliable method to evaluate the ecological effect (restoration effect, i.e., effect of restoration on both biodiversity and ecosystem services) of the restoration practice is needed. To fill this gap, a comprehensive assessment index system, based on the "driving forces-pressures-state-impacts-responses" (DPSIR) model was established to holistically evaluate the overall ecological effect of a polluted urban river (the Nanfei River) during restoration. Our results revealed that the greatest influence on the river ecosystem came from: cultivated areas, gross domestic product, ammonia nitrogen (NH_4^+-N) and total phosphorus (TP) emissions from large-scale aquaculture, non-point rainfall runoff, and municipal sectors. In addition, the river restoration implementation positively influenced the polluted urban river ecosystem. During our study period, a trend of parallel increase between biodiversity and ecosystem services was existed, and an approximate positive relationship between ecosystem services and restoration age was found. However, the detailed relationship patterns between biodiversity, ecosystem services and restoration age should be revealed by long-term monitoring. Overall, the method proposed in our study would improve the understanding of restoration practice, and provide guidance for future restoration practice assessment.

1. Introduction

Being the important carrier of resource and environment, river ecosystem has multiple functions including system regulation, and ecological and social service provision (Pinto and Maheshwari, 2011). In particular, urban rivers often support commerce, industry, and transportation (e.g., municipal and industrial water supplies) of a city (Smith et al., 2016), which plays a significant role in the sustainable development of a city. However, under the pressure of a variety of human activities, such as industrialization or urbanization, some urban rivers have changed from dynamic and diverse ecosystems to being static and homogeneous ones, leading to a deterioration in biodiversity and ecosystem functions (Booth and Fischenich, 2015; Rios-Touma et al., 2015; Chen et al., 2018). Hence, to achieve sustainable urban development by maintaining or improving the biodiversity and function of the urban river ecosystem, increasing attention is being paid to the restoration of impaired urban rivers, both in developed and developing countries (Jia et al., 2014; Kurth and Schirmer, 2014; Viswanathan and Schirmer, 2015).

Numerous river restoration projects have been conducted around the world, and the restoration measures are becoming increasingly diverse and mature, especially in Europe (Renöfält et al., 2013; Neale and Moffett, 2016; Kupilas et al., 2017), America (Unghire et al., 2011; McMillan et al., 2014; Reeves et al., 2016), and Asia (Nakano and Nakamura, 2008; Wu et al., 2013; Li et al., 2014). Restoration measures have included wood/gravel/boulder addition (Acuña et al., 2013; Dolph et al., 2015; Pander et al., 2015), channel reconfiguration (Helfield et al., 2012; Besacier-Monbertrand et al., 2014; Hering et al., 2015), and the establishment of riparian buffers (Thompson and Parkinson, 2011; Mi et al, 2015; Vandermyde and Whiles, 2015). Restoration measures are becoming increasingly advanced. However, urban environments are difficult to work in because of political considerations, and there are relatively less reports on urban river restoration (Thompson and Parkinson, 2011).

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Despite the rapid spread of river restoration projects, monitoring and evaluation of the ecological effects (i.e., restoration effect, including the change of biodiversity and ecosystem services of the river restoration) have not been performed in a standardized way (Bernhardt et al., 2005; Kupilas et al., 2017). The evaluation of ecological effects is, however, critical to any scientific and practical progress in river restoration (Palmer et al., 2005; Lee and An, 2014). Existing studies have used a single index method and a multi-metric approach to assess the ecological effect of river restoration, which always failed to assess the ecological effect from a systematic perspective. Studies using the single index method mainly centered on biological/trophic indicators of fish (Baldigo et al., 2008; Antón et al., 2011) or invertebrates (Tullos et al., 2009; Giling et al., 2016), with fish indexes being the most frequently used. Regarding studies adopting multi-metric approach, they usually included the physical, chemical and biological aspects (Wu et al., 2013; Lee and An, 2014). Studies assessing restoration effects mainly focused on changes in biodiversity (Teels et al., 2006; Forget and Bernez, 2011), while only a few focused on changes to ecosystem functions or services (McMillan et al., 2014; Pander et al., 2015; Kupilas et al., 2016). To the best of our knowledge, limited study among the existing peer-reviewed literature have analyzed the relationship between biodiversity and ecosystem services within restoration projects. In addition, there may even be no adequate monitoring and evaluation of the restoration setting (i.e., restoration age) influencing the restoration effect (Hering et al., 2015).

Although the existing research on assessing restoration effects has contributed much information regarding river restoration, limitations still exist in providing guidance for future river restoration implementation. For example, contrasting results might be obtained when choosing a single index method to evaluate the restoration effect. Some studies have shown that restoration had significant positive effects on certain organism groups (Schmitz et al., 2009; de Jong and Cowx, 2016), while others found little, or even no, effect on benthic invertebrates (Friberg et al., 2014; Lepori et al., 2005), macrophytes (Lorenz et al., 2012; Pedersen et al., 2007), or fish (Lorenz et al., 2013; Schmutz et al., 2014). Hence, an integrative assessment method based on the “driving force-pressure-state-impact-response” (DPSIR) model, which combines the socio-economic and environmental systems, was used in this study.

The DPSIR framework is a powerful, system-oriented, modeling technique, which assumes cause-effect relationships between interacting components of socio-economic and environmental systems (Bradley and Yee, 2015). Developed by the European Environmental Agency (EEA) in 1999 (Bosch et al., 1999), the DPSIR framework has been widely applied in various fields; e.g., agricultural systems (Lin et al., 2013; Zhou et al., 2013), river systems (Kagalou et al., 2012), soil systems (Pullanikkatil et al., 2016), and marine systems (Nuttle and Fletcher, 2013).

The aims of this study are: (1) to introduce a comprehensive assessment index system based on the DPSIR model to river restoration project assessment, and applied it to assess the ecological effect of an urban river restoration project (the Nanfei River in Hefei City, China); (2) to identify key factors influencing ecological effects in the river ecosystem using the comprehensive assessment index system; and (3) to investigate the relationship between the change of biodiversity and ecosystem services and to reveal the influence of the restoration age.

2. Materials and methods

2.1. Study area and sampling points of the Nanfei River

The Nanfei River is located in the northwest of Chaohu Lake (Hefei City, Anhui Province, China), with a total length of 71 km and a catchment area of 1464 km^2 (see in Fig. 1). It flows through five districts (Shushan, Luyang, Yaohai, Xinzhan, and Baohe Districts) and two counties (Changfeng County and Feidong County). Since the interception of upstream water sources by the Dongpu Reservoir, the Nanfei River basically becomes a river without water source except for natural water supply of rainfall. In addition, the river receives a lot of non-point source pollution and effluent from wastewater treatment plants, leading to extremely poor river water quality. In 2008, the average water quality of the Nanfei River was lower than grade V under China’s Environmental Quality Standards for Surface Water (GB3838-2002) (Environmental Protection Agency of China, 2002). To improve the water quality and restore the ecosystem status of the Nanfei River, restoration activities were carried out on the upstream (from Dongpu Reservoir to Hezuohua Road) of the Nanfei River from October 2009 to April 2011 (Wu et al., 2013).

Measures of ecological riparian establishment (sites 2#, 4#, 6#, 8#), ecological filter bed construction, combined ecological floating island (sites 2#, 6#) and vegetation replanting in river channel (sites 1#, 2#, 3#, 4#, 6#, 8#, 9#) were adopted (seen in Fig. 1). In these measures, a total of 14 species of indigenous and prevalent macrophytes were planted in bands along the bank slopes and in the river. The species included eight emergent species (*Pontederia cordata*, *Thalia dealbata*, *Iris pseudacorus*, *Canna generalis*, *Acorus calamus*, *Lythrum salicaria*, *Cyperus alternifolius*, and *Iris hexagonus*), one floating-leaved species (*Nymphaea tetragona*), and five submerged species (*Potamogeton crispus*, *Ceraophyllum demersum*, *Vallisneria natans*, *Myriophyllum spicatum*, and *Hydrilla verticillata*). The reasons for choosing these species included both their original presence in this area before degradation, and their contribution to an improved scenic effect. From August 21, 2009, water samples were collected monthly, and physicochemical parameters, i.e., total nitrogen (TN), TP, NH_4^+-N, chemical oxygen demand (COD), oxygen demand (OD), pH, Chlorophyll *a*, and transparency were monitored. Samples of phytoplankton and zooplankton were also obtained seasonally from 2010. To reveal the change of the overall ecological effects during the restoration process, we chose the samples in 2010 (initial stage of restoration) and 2015 (a short period after restoration) as our study period.

2.2. Conceptual framework of DPSIR

The components of DPSIR and the relationship among different components of the DPSIR conceptual framework can be seen in Fig. 2.

(1) Driving forces (D) are always seen as the essential conditions and materials for factors such as a high standard of living, and security. The potential driving forces could be social, demographic, and economic developments. With their intuitions and accessibilities, driving forces refer to the economic sector in many studies, while not to the social sector. Hence, in this study area, the driving forces indicators relating to the development of the socio-economy were considered to the urbanization rates of planning areas, natural population growth rates, GDP, and the cultivated area of the river basin.
(2) Pressures refer to human activities, i.e., the production or consumption process to meet the needs resulting from driving forces. There are three main types: excessive use of natural resources; emissions to the environment; and changes in land use. By considering the nature and data availability for various pressures, the following pressure indicators were chosen: emissions of TN, TP, and COD from municipal, industrial, and large-scale aquaculture sectors, and rainfall runoff pollution.
(3) State refers to the quality of various environmental components (e.g., water, air, and soil) as a result of the pressures exerted on the environment, and is a combination of physical, chemical, and biological conditions. Based on data accessibility, the physical and chemical indicators (TN, TP, COD, NH_4^+-N, DO, transparency, and Chlorophyll *a*) of water quality and biological indicators (diversity of phytoplankton and zooplankton) were defined as “state” indicators for this study.