Journal of Hydrology 523 (2015) 384–397

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Linking hydrologic, physical and chemical habitat environments for the potential assessment of fish community rehabilitation in a developing city

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A R T I C L E I N F O

Article history:
Received 22 December 2014
Received in revised form 27 January 2015
Accepted 30 January 2015
Available online 9 February 2015
This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Hydrology
Water quality
Rehabilitation potential
Habitat suitability
Ecological niche
Fish assemblage

S U M M A R Y

Aquatic ecological rehabilitation is increasingly attracting considerable public and research attention. An effective method that requires less data and expertise would help in the assessment of rehabilitation potential and in the monitoring of rehabilitation activities as complicated theories and excessive data requirements on assemblage information make many current assessment models expensive and limit their wide use. This paper presents an assessment model for restoration potential which successfully links hydrologic, physical and chemical habitat factors to fish assemblage attributes drawn from monitoring datasets on hydrology, water quality and fish assemblages at a total of 144 sites, where 5084 fish were sampled and tested. In this model three newly developed sub-models, integrated habitat index (*IHSI*), integrated ecological niche breadth (*INB*) and integrated ecological niche overlap (*INO*), are established to study spatial heterogeneity of the restoration potential of fish assemblages based on gradient methods of habitat suitability index and ecological niche models. To reduce uncertainties in the model, as many fish species as possible, including important native fish, were selected as dominant species with monitoring occurring over several seasons to comprehensively select key habitat factors. Furthermore, a detrended correspondence analysis (DCA) was employed prior to a canonical correspondence analysis (CCA) of the data to avoid the "arc effect" in the selection of key habitat factors. Application of the model to data collected at Jinan City, China proved effective reveals that three lower potential regions that should be targeted in future aquatic ecosystem rehabilitation programs. They were well validated by the distribution of two habitat parameters: river width and transparency. River width positively influenced and transparency negatively influenced fish assemblages. The model can be applied for monitoring the effects of fish assemblage restoration. This has large ramifications for the restoration of aquatic ecosystems and spatial heterogeneity of fish assemblages all over the world.

1. Introduction

Globally, intensive human activities have been changing riverine environments in terms of their hydrology, pollutant loads and habitat attributes (Walters et al., 2009). Species in aquatic ecosystems that are intolerant of these changes can decline or disappear and are replaced by organisms that are more tolerant (Fraker et al., 2002; Helms et al., 2005; Morgan and Cushman, 2005; Kemp, 2014). For instance, in a large area of shifting riparian, marsh and estuarine ecosystems, the remnants of these aquatic ecosystems are largely fixed in place and cut off from each other by water management structures (Zamora et al., 2005; Glenn et al., 2013). This has been repeated around the world and in the USA the construction of 75,000 dams has contributed to declines of native fish populations (Osmundson, 2011). Many stressed

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http://dx.doi.org/10.1016/j.jhydrol.2015.01.067
0022-1694/

rivers are resilient and can recover from degraded conditions after restoration activities as habitats are often naturally dynamic and frequently experience large-scale natural disturbances such as floods (Kauffman et al., 1995; Moerke et al., 2004; Hansen and Budy, 2011). Suitable habitats are very important for the species survival and diversity in aquatic ecosystems. Improvement or at least maintenance of habitats is therefore necessary for the recovery of aquatic ecosystems (Bellmore et al., 2012). As a result, river restoration requires the identification of environmental and pressure gradients that affect river systems and the selection of suitable indicators to assess habitat quality before, during and after restoration (Hughes et al., 2010).

Over several decades river habitat restoration has been utilized as a strategy to recover and conserve threatened and endangered species (Bernhardt et al., 2005). However, the success of habitat restoration is often uncertain (Wissmar and Bisson, 2003), for example, the successful restoration of only the physical habitat does not guarantee success. Information about the response of aquatic species to hydrologic, physical and chemical environments is therefore needed to better understand the potential for habitat restoration (Bellmore et al., 2012). Further, periodical assessment of the rehabilitation potential is required to measure success.

Current potential assessment methods are often too difficult to use in practice by river administrators and stakeholders because of a need for multidisciplinary knowledge, e.g., biology, hydrology and ecology. Generally, previous assessment approaches focus on specific species (e.g., endangered, threatened or native species) (Palmer et al., 2005; Bain and Meixler, 2008), bioindicators (Hughes, 2005; Feld and Hering, 2007; Vaughn et al., 2007; Hughes et al., 2010), recruitment index (Armstrong and Hightower, 2002; Fox, 2004) or detection of impaired habitat and/or processes (Bellmore et al., 2012). Successful implementation of these methods depends critically on connecting the underrepresented taxa with the mechanisms responsible for their reduction/elimination but often requires substantial scientific expertise. Although many previous studies have related human activities to resident species assemblages, few have confirmed or determined mechanisms (Peoples et al., 2011; Kemp, 2014). Common bioindicators often include benthic macroinvertebrates, fish, benthic diatoms, macrophytes and birds (Feld and Hering, 2007; Vaughn et al., 2007; Hughes et al., 2010). An effective bioindicator should exhibit detectable and measurable changes in relation to specific environmental or pressure gradients, ideally starting from reference conditions (Johnson et al., 2006; Karr and Chu, 2000; Paavola et al., 2006; Hughes et al., 2010). In addition, some methods require the selection of specific restoration sites based on the outcome of watershed-level assessments (Roni et al., 2002; Pess et al., 2003; Bellmore et al., 2012). However, for many rivers the information required was not available (Osmundson, 2011). An effective method that requires less data and expertise would help in the assessment of rehabilitation potential and in the monitoring of rehabilitation activities.

Fish communities are effective ecosystem indicators as they are relatively easy to identify, and their position at the top of the food chain helps provide an integrative view of the environment (Wu et al., 2014). Some habitat restoration programs have taken fish as representative of ecosystems health to evaluate aquatic ecosystem restoration potential, e.g., the use of the Endangered Species Act – listed anadromous Pacific salmon and steelhead populations in the United States (Bernhardt et al., 2005; Bellmore et al., 2012). Habitat type and complexity, or habitat heterogeneity, influence resource use by many fish species (Okun and Mehner, 2005; Visintainer et al., 2006) along with biological interactions, such as competition and predation (Coen et al., 1981; Danielson, 1991; Whitley and Bollens, 2014). Therefore, understanding the response of fish to habitat variation is important for monitoring their rehabilitation potential.

The objective of this paper is to develop an effective method for assessment of rehabilitation potential based on the responses of dominant fish species to their habitat environment. It has relatively simple theory (habitat gradient theory: habitat suitability and ecological niche), requiring only basic information and expertise (fish assemblage: only the number and biomass of fish species; fish names are unnecessary). These easily recorded fish attributes are linked to habitat environmental gradients of hydrologic, physical and chemical parameters to determine dominant species, select key habitat factors and assess the rehabilitation potential of fish communities.

2. Study area

Jinan City (36.0–37.5°N, 116.2–117.7°E) is bordered by Mount Tai to the south and traversed by the Yellow River and has a steeper topography in the south than in the north (Fig. 1). Hilly areas, piedmont clinoplain and alluvial plains span the city from south to north. The altitude within the area ranges from −66 to 957 m above sea level, with highly contrasting relief. The semi-humid continental monsoon climate in the city area is characterized by cold, dry winters and hot, wet summers. The average annual precipitation is 636 mm 75% of which falling during the high-flow periods. The average annual temperature is 14.3 °C. The average monthly temperature is highest in July, ranging from 26.8 to 27.4 °C, and is lowest in January, ranging from −3.2 to −1.4 °C (Cui et al., 2009; Zhang et al., 2010).

The city represents a typical developing city in China, with an area of 8227 km^2 and a population of 5.69 million (Zhang et al., 2007). With rapid industrial development and urbanization in recent decades, the water resources in Jinan are severely polluted and reduced in quantity through extraction. As a result, drinking water, human health and well-being are being increasingly threatened (Hong et al., 2010) as well as the fish community. Policymakers and stakeholders are aware of the need to rehabilitate the aquatic ecosystems in Jinan City. To facilitate research program on rehabilitating these aquatic ecosystems, the entire city was divided into four eco-regions (Yu et al., 2014) and 48 routine monitoring stations distributed evenly on typical rivers were set up (Fig. 1). At these monitoring stations 37 parameters including hydrologic, physical and chemical environmental factors are concurrently measured (Table 1). To ensure successful aquatic ecosystem restoration over all river sections, river administrators and stakeholders urgently require an easy-to-use method to periodically assess their rehabilitation success.

In the research of Yu et al. (2014) three-level eco-regions were classified with geographic information system (ArcGIS) and spatial autocorrelation analysis. Meanwhile the first-level eco-region mainly take as basis the characteristics of the city administrative divisions and river watersheds. It is mainly composed of three watersheds of the Yellow, Xiaoqing and Tuhaimajia rivers as well as the city urban area. The classification of the second-level eco-region mainly considers spatial pattern of land use. Based on the second-level eco-region the classification of the third-level eco-region was conducted, where the clustering analysis was conducted with water quality indices at sampling sites. In the present study we take the first-level eco-region as basis to assess fish rehabilitation potential.

3. Data

To explore the response of fish species to habitat factors, we conducted three extensive field campaigns to monitor the fish community and concurrently their habitat attributes. These attributes were primarily classified into hydrologic, physical and