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Research papers

Quantifying effects of hydrological and water quality disturbances on fish with food-web modeling

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ABSTRACT

Accurately delineating the effects of hydrological and water quality habitat factors on the aquatic biota will significantly assist the management of water resources and restoration of river ecosystems. However, current models fail to comprehensively consider the effects of multiple habitat factors on the development of fish species. In this study, a dynamic framework for river ecosystems was set up to explore the effects of multiple habitat factors in terms of hydrology and water quality on the fish community in rivers. To achieve this the biomechanical forms of the relationships between hydrology, water quality, and aquatic organisms were determined. The developing processes of the food web without external disturbance were simulated by 208 models, constructed using Ecopath With Ecosim (EWE). These models were then used to analyze changes in biomass (ΔB) of two representative fish species, *Opsariichthys bidens* and *Carassius auratus,* which are widely distributed in Asia, and thus have attracted the attention of scholars and stakeholders, due to the consequence of habitat alteration. Results showed that the relationship between the changes in fish biomass and key habitat factors can be expressed in a unified form. T-tests for the unified form revealed that the means of the two data sets of simulated and observed ΔB for these two fish species (*O. bidens* and *C. auratus*) were equal at the significance level of 5%. Compared with other ecological dynamic models, our framework includes theories that are easy to understand and has modest requirements for assembly and scientific expertise. Moreover, this framework can objectively assess the influence of hydrological and water quality variance on aquatic biota with simpler theory and little expertise. Therefore, it is easy to be put into practice and can provide a scientific support for decisions in ecological restoration made by river administrators and stakeholders across the world.

1. Introduction

Globally, climate change and intensive human activity have led to alterations in the water cycle and river environments (such as the hydrological status, pollutant load, and habitat attributes), which have damaged the ecological integrity and ecosystem service values of rivers (Joniak and Kuczyńska-Kippen, 2010; Marzin et al., 2014; Zhu et al., 2014). The degradation of river ecosystems and river health is a major crisis, which has greatly affected the survival of human beings and the sustainable development of society in the 21st century (Tang et al., 2002). To alleviate the degradation trend, river ecosystem management projects are carried out globally (Zhao et al., 2014, 2015a). However, the complicated mechanisms acting between various habitat factors are not clear, which has led to limited success in river governance with great wastage in manpower and material resources (Suding et al., 2015).

As an effective tool for exploring the complex interactions between various habitat factors as hydrological or water quality indices in an ecosystem, the ecosystem model focuses on key physical, chemical and biological processes, and the relationships between various factors (Zheng et al., 2012; Li et al., 2013; Li and Davis, 2016). It is therefore important approach to determine

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how external interferences affect the ecosystem (Steinacher et al., 2010; Li et al., 2013). However, most previous studies have focused on the ecological simulation of algae and zooplankton, while the riverine benthic animals and fishes are rarely studied (Chen et al., 1997; Arhonditsis and Brett, 2004; Arhonditsis et al., 2006; Vera-Mendoza and Salas-de-León, 2014). This is not conducive to providing an overall grasp of the biological condition of the impacted river. Additionally, most previous research has tended to study the effects of single factors (such as nitrogen and phosphorus) on aquatic organisms, with few studies considering the synergistic effects of several factors (Chen et al., 2002; Liu and Dagg, 2003; Middelburg and Levin, 2009; Sell, 2004). Because of the complexity of ecological systems, assessing habitat condition is not simply the sum of individual factors (Meng et al., 2009; Zhu et al., 2014), and recent studies have not been conducive to a comprehensive understanding of the effects of environmental factors on aquatic organisms (Deng et al., 2015), which has hindered the progress of river ecosystem restoration.

In river ecosystems, fish are the most important group of organisms, and play important roles in nutrient cycling and energy flow. Fish communities are effective ecosystem indicators as they are relatively easy to identify (Zhang et al., 2007; Huo et al., 2013), and their position at the top of the food web helps to provide an integrated view of the environment (Wu et al., 2014). Some habitat restoration programs have taken fish as representative of an ecosystem's health to evaluate the potential of river ecosystem restoration (Bellmore et al., 2012; Whitley and Bollens, 2014). As such, there is an urgent need to synthetically consider the effects of multiple factors on aquatic life taking fish as representatives, and to construct a new dynamic model of river ecosystems based on the response of aquatic life to multiple factors.

In this study, the Ecosim, a time dynamic ecological simulation model, was used to simulate the development of a complete food web in an ecosystem without external forces. Based on the super-dimensional data sets composed of hydrological and water quality factors, which are the principal driving factors for river fish, a principal component analysis (PCA) was used to reduce the dimension of the hyper-dimensional data sets and to generate new sets of independent influencing factors. Based on the study on the relationship between fish and their habitat factors of hydrology and water quality, a numerical framework of ecosystem dynamics was established to provide scientific support for ecological management and restoration of rivers.

2. Study area

The city of Jinan (36.0–37.5 °N, 116.2–117.7 °E) is located in eastern China, 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; Zhao et al., 2015b)

The city represents a typical developing city in China, with an area of 8227 km^2 and a population of 5.69 million people (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. As a result drinking water, human health and well-being are being increasingly threatened as well as the fish community (Hong et al., 2010; Zhao et al., 2015b). Policymakers and stakeholders are aware of the need to rehabilitate the river ecosystems in the city, and routine monitoring stations distributed evenly on typical rivers were established (Fig. 1). At these monitoring stations, parameters relative to biota, water quality, and hydrological factors were measured concurrently.

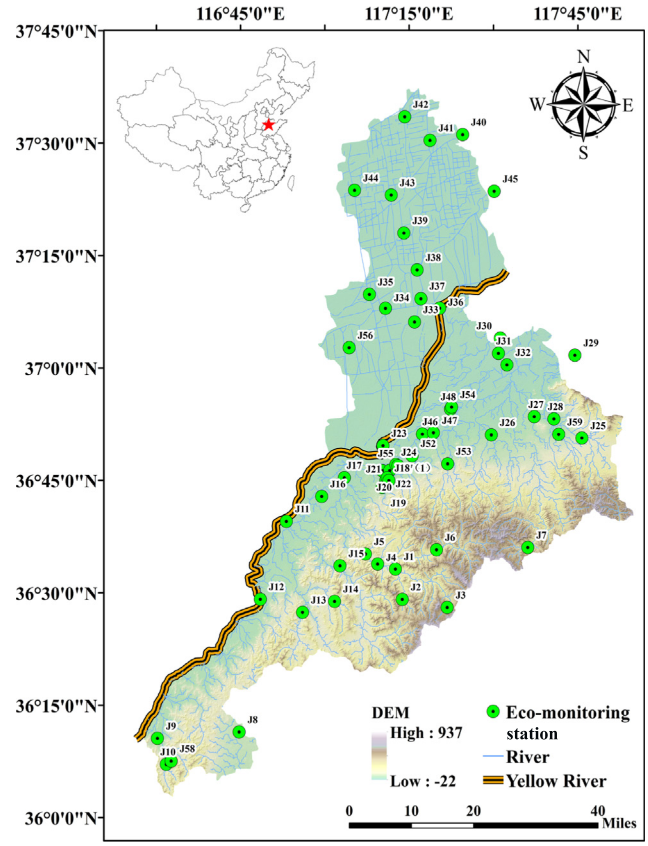

Fig. 1. Study area with routine hydrology-water quality-river ecosystem monitoring stations.

3. Materials and methods

3.1. Data

We collected samples from 57 water ecological monitoring sites in Jinan. Sampling was performed eight times between May 2014 and July 2016. Biological data (algae, zooplankton, zoobenthos, fish) and habitat (hydrological and water quality) data were concurrently collected.

3.1.1. Biological data

Over the eight sampling events, 58 taxa of fish samples were collected, belonging to one phylum, one class, seven orders, 19 families, and 50 genera. Fish were collected over 30 min in three habitat types (i.e., pools, riffles, and runs) within a 500 m reach along the river at each sampling site. Individuals caught from the three habitats were combined to represent a site. In addition, electrofishing was conducted to ensure that a good representation of fish species was collected at each site. All individuals collected were identified to species where possible in situ as described by Chen et al. (1997) and then counted, weighed, and recorded in field data sheets. All identified fish were then released. A few specimens that could not be identified in the field were preserved in 10%