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ECOENG-2987; No. of Pages 12

ARTICLE IN PRESS

Ecological Engineering xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

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

Response of fish communities to environmental changes in an agriculturally dominated watershed (Liao River Basin) in northeastern China

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ARTICLE INFO

Article history:
Received 23 December 2013
Received in revised form 12 April 2014
Accepted 19 April 2014
Available online xxx

Keywords:
Anthropogenic activities
Agriculture
Urban industry
Fish communities
Longitudinal gradient
Liao River Basin

ABSTRACT

The aims of this study were to identify the species distribution pattern at local and watershed scales, the response to variation of environmental conditions, and the local factors structuring fish communities in Liao River Basin. A total of 187 sites were sampled during May 2009 to June 2010. Univariate and multivariate methods were conducted to identify the variation of species richness and composition. We identified 56 species in the basin, and the predominant orders were Cypriniformes (33 species) and Perciformes (10 species). Species richness degraded seriously (from 106 to 56 species) compared with the data obtained during the 1980s. Based on the similarity of fish communities, the sampling sites were divided into three groups. Group 1 was distributed in the Hun-Tai River Basin located in the southeast region with less anthropogenic disturbance, and was characterized by high physical habitat quality (high velocity, habitat score, and coarse substrate) and water quality. The other two groups were mainly distributed in the main stem and its tributaries, with more stress (high conductivity, COD_{Mn}, NH_4^+, and sand substrate) caused by agriculture and urban industry. Species richness increased along a longitudinal gradient and reached the maximum in Group 2. The distribution pattern of fish communities was analogue with the scheme of the Grade I aquatic eco-functional zonings and can be used as a good indicator with high verification ability. The indicator species of Group 1 were all small-sized and sensitive to environmental stress, while those species of Groups 2 and 3 were more tolerant. Physical habitat (velocity, habitat score, cobble plus boulder, and dissolved oxygen) and chemical pollutants (NH_4^+, COD_{Mn}, conductivity, and TN) structured the fish communities at the local scale. The degradation of environmental condition reduced physical habitat, water quality, and sensitive taxa in the downstream sections of Liao River Basin.

1. Introduction

The effects of anthropogenic activities on freshwater ecosystems have been frequently cited since the degradation of physical habitat condition and discharge of contaminated water have profound and lasting impacts on the ecosystem (Allan and Flecker, 1993; Clavero et al., 2004; Dodds, 2002; Ferreira et al., 2007; Mason, 1991). Many studies have been conducted on the terrestrial ecosystem to identify how organisms respond to changes in environmental characteristics (Chen et al., 2000; Kennedy, 1995), and more attention is increasingly paid to the conservation of freshwater organisms (Benedetti-Cecchi et al., 2001; Harding et al., 1998; Jiang et al., 2010; Murchie et al., 2008). Knowledge of the fundamental characteristics of biological communities and their responses to altered environmental conditions is the first step toward the development of effective conservation strategies. Physical habitat, water quality, and fish communities have been monitored as indicators for assessing stream health under watershed development (Allan, 2004; Karr, 1981; Maddock, 1999; Singh et al., 2005). On account of the advantages of being a good bioindicator, such as their ease of capture and identification and generally known life history, trophic habits, and ecological requirements (Oberdorff et al., 2001), fish communities have been used to test ecological integrity since the 1980s (Karr, 1981). Besides, as fish are the top predators in the food web, we can gain an integrated insight of the whole freshwater ecosystem (Chalar et al., 2013).

Anthropogenic activities have changed and degraded environmental conditions in multiple ways, such as through nonpoint source contaminants from agriculture (Sponseller et al., 2001), point source contaminants from industrial and municipal

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http://dx.doi.org/10.1016/j.ecoleng.2014.04.019
0925-8574/

discharges (Fu, 2008), and hydrological transformations from dams and withdrawals for water supply (Poff et al., 1997). These stressors have caused destructive effects on the biological communities and ecosystem integrity by discharging nutrients, depositing sediment and chemical pollutants, modifying watercourse geomorphology and riparian habitat, and altering hydrological, light, and temperature regimes of freshwater systems (Allan, 2004; May, 2006; Newson and Newson, 2000). Bioassessment using fish communities has become more common in recent years as a convenient and effective tool to detect the degradation of freshwater ecosystems in China and some other Asian countries (Fu et al., 2003; Yap, 2002; Zhong and Power, 1996). However, the ecological information about the distribution patterns of fish communities and their response to changing environmental conditions under the temperate climate in China is still limited. Due to the natural environment conditions, especially the annual average temperature, altitude, annual precipitation and landscape characteristics, the fish distribution type of China have been divided into five faunas (Li, 1981). For each different fauna, the community structure, ecological habit and local species were disparate and the relevant researches for the effect of changed environmental conditions on fish community were almost concentrated in the south of China (Fu et al., 2003; Nie et al., 2005). The Liao River Basin, with a temperate monsoon climate, is the seventh largest watershed in northeast of China. During the last two decades, the developments of agriculture and urban industry have considerably changed the environmental condition, especially in the middle and lower reaches (Li et al., 2012). Current studies have claimed that the water resources of Liao River Basin have undergone contamination by several types of severe pollutants from agriculture and industrial wastewater (Zhang et al., 2008). In the middle and lower reaches, the cultivated and urban land increased, and woodland, grassland and water area diminished accompanied the increase of population and development of economies. The changes of land use have caused serious degradation in aquatic ecosystem, including intensive soil erosion, water resources shortage, deterioration of water quality and ecological function degradation (Huang et al., 2004). Based on the physical-chemical parameters for water quality, aquatic life index and physical habitat quality index, Zhang et al. (2009) conducted the multi-variable assessment method to evaluate the synthetical ecological condition of Liao River Basin, and the results indicated that all the sick and sub-sick sites were located in the mid-downstreams.

Previous studies showed that the variation of community composition could be predicted by the River Continuum Concept (RCC; Vannote et al., 1980) along the longitudinal gradient. Therefore, Poff (1997) debated that the input of organic matter combined with the constraining effect of hydrological features may shift the species richness and communities by changing the food resources, physical habitat, and water quality. Thus, the objectives of the current study were to determine: (1) how many species remain and the level of degradation in Liao River Basin; (2) how the fish communities responded to the variation of environmental parameters, and whether the species distribution pattern conformed to the RCC; and (3) which local environmental parameters could be used as good indicators to explain fish composition in Liao River Basin.

2. Materials and methods

2.1. Study area

Liao River Basin (40°30′–45°10′N, 117°00′–125°30′E; Fig. 1) is located in northeastern China and encompasses the entirety of Liaoning Province and parts of Inner Mongolia Autonomous Region and Hebei and Jilin Provinces. The total drainage area is 229,000 km^2 and the mainstem and major tributaries have a total stream length of 1430 km. The predominant land use is agriculture (38.29%), followed by grassland (23.65%), forest (22.78%), bare land (6.45%), residential land (4.43%), and water body (4.4%). The upstream areas of the southeast, southwest, and northwest regions are dominated by forest and grassland. The middle and downstream regions are dominated by agriculture and scattered grassland and urban industrial land (Li et al., 2012). Annual precipitation increases from northwest to southeast and ranges from 350 to 900 mm. There are seven main rivers: Xila' Mulun, Laoha, West Liao, East Liao, Hun, Taizi, and Daliao Rivers (numbered 1–8, respectively, in Fig. 1). Xila' Mulun, Laoha, and West Liao Rivers have been in drought for years. A total of 187 sampling sites were surveyed from May 2009 to June 2010 (Fig. 1).

2.2. Field sampling and environmental parameters

Fish were caught within a 300-m survey range using ultrasonic electrofishing equipment for wadeable streams. Gill nets (60 m long, 1 m wide, 2 cm mesh) were used for non-wadeable rivers for a 1-h fixed period of time. All fish were counted and identified to the species level. Except for unknown species, the remaining fish were released back to the river. The un-identified species were brought back to the laboratory for further identification.

Before sampling fish, in-situ measurements were conducted, including point coordinates (Explorist-200, Magellan, San Dimas, CA), water temperature (WT, °C), conductivity (μS/cm), dissolved oxygen (DO, mg/L), pH (YSI-80, YSI Inc., Yellow Springs, OH), depth (m), and velocity (m/s) (FP101, Geotech Environmental Equipment, Inc., Denver, CO). Chemical parameters, including alkalinity (mmol/L), biochemical oxygen demand (BOD_5, mg/L), chemical oxygen demand (COD_{Mn}, mg/L), nitrite (NO_2^-, mg/L), nitrate (NO_3^-, mg/L), ammonium (NH_4^+, mg/L), total nitrogen (TN, mg/L), and total phosphorus (TP, mg/L) were sampled and tested following standard methods (Environmental Quality Standards for Surface Water, GB 3838-2002) (SEPA and AQSIQ, 2002).

Predominant substrate was assigned into one of three types: (i) cobble plus boulder (CPB), (ii) pebble plus gravel (PPG), and (iii) sand, according to the modified criteria of Jiang et al. (2010). The habitat score (HS) was calculated followed the criteria of Barbour et al. (1999).

2.3. Statistical analysis

All sampling sites were divided into different groups based on the similarity of fish communities, as determined by cluster analysis (Sørensen distance measure and Bray–Curtis similarity) (McCune and Mefford, 1999). The multi-response permutation procedure (MRPP), a nonparametric statistical process using the Monte Carlo randomization procedure, was conducted to discriminate the significance among different groups. Three assemblage parameters were calculated: species richness, Shannon–Wiener diversity index (H'), and Berger Parker index (BP). Richness was calculated by counting all the taxa for each site, while H' and BP were calculated, respectively, as follows:

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i$$

$$BP = \frac{P_{max}}{\sum_{i=1}^{S} P_i}$$

where S is the total number of taxa, P_i is the relative abundance of species i, and P_{max} is the abundance of the most dominant species.