Ecological Modelling 353 (2017) 63–76

Contents lists available at ScienceDirect

Ecological Modelling

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

Evaluation of river habitat integrity based on benthic macroinvertebrate-based multi-metric model

Xuan Shi, Jingling Liu*, Xiaoguang You, Kun Bao, Bo Meng, Bin Chen

State Key Joint Laboratory of Environmental Situlation and Pollution Control, School of Environment, Beijing Normal University, 100875 Beijing, PR China

ARTICLE INFO

Article history:
Received 2 February 2016
Received in revised form 28 June 2016
Accepted 3 July 2016
Available online 9 August 2016

Keywords:
Benthic macroinvertebrate-based multi-metric model
River habitat integrity
Benthic macroinvertebrates
Habitat restoration

ABSTRACT

Considering relationships between environmental factors and aquatic ecosystems, obtaining a clear understanding of river habitat integrity plays a key role in addressing habitats' disturbances. Since benthic macroinvertebrate assembly can reflect the benthic stream conditions, we assessed the river habitat integrity based on benthic macroinvertebrate multi-metric model. The development and application of Benthic macroinvertebrate multi-metric index (B-MMI) was based on samples collected from October to November 2014 at representative sites from upper to lower reaches in Luanhe River, Haihe River Basin, China. Hydromorphology, water quality and land use patterns were considered to define reference sites and metrics related to macroinvertebrate community composition, structure, function and tolerance to pollution were selected as candidate metrics. Then, Range, sensitivity and redundancy tests were used to select candidate metrics based on their ability to distinguish the reference and impaired sites. As the result, four core indicators were selected to build the B-MMI: EPT%, Tubificidae%, BI (Biotic Index), Collect-Gatherers%. The values of B-MMI ranged from 0.21 to 3.75 in 17 sites. Based on B-MMI values, the habitat integrity of 29% sites were in very poor status and 6% were in excellent status. The upper reaches were influenced by animal husbandry and tourism, while the lower reaches were influenced by urbanization and dams. More good habitats were located in middle reaches under less human disturbances. Overall, this B-MMI shows promise for developing biomonitoring tools to assess the habitat integrity of streams, to provide appropriate restoration strategies and policies.

1. Introduction

River ecosystems are characterized by complex interactions between physical, chemical, and biological systems and natural processes, each operating at different characteristic special scale (reach to watershed) and frequencies (Danehy et al., 2012; Parasiewicz et al., 2012; Alldredge and Moore, 2014; Zhang and Liu, 2014b; Valero et al., 2015). Yet increasingly intensive human activities have been changing aquatic physical habitat conditions (Poff et al., 2010; Remo et al., 2013; Belmar et al., 2013; Boykin et al., 2013; Johnson and Ringler, 2014; Zhang and Liu, 2014a; Yan et al., 2014; Zhao et al., 2015; Shen et al., 2015). Water abstraction, pollution, channelization, damming, agriculture and other pressures lead to hydrological changes and then the distribution of habitats are influenced, which will severely affect the ecological health of aquatic environments and their biota (Schmitter-Soto et al., 2011; Marzin et al., 2012; Matono et al., 2012; Li et al., 2013). Furthermore, efficient river management and habitat restoration efforts urgently need instruments to evaluate the biotic response to these problems, to identify the most vulnerable sites, or to set goals for eventual rehabilitation efforts (Schmitter-Soto et al., 2011; Julie and Williams, 2013).

In present studies, interests in the assessment of habitat ecological integrity and its applications to riverine physical habitat management have been globally increasing (Liedloff et al., 2013; Michez et al., 2013; Van den Brink et al., 2013; Victor Cortes et al., 2013; Taylor et al., 2013; Baek et al., 2014). However, these studies were more focused on fish communities and on specific species (e.g., endangered, threatened, or native species) especially in habitat suitability studies (Lyons, 2012; Yi et al., 2010a; Vezza et al., 2014b; Zhao et al., 2015). Instead, the structures of whole communities need to be assessed for some rivers with few scarce species. And there are few studies investigating the relationships between hydrology and ecology in different hydromorphological types. The relationships between hydromorphological parameters and aquatic ecosystems are the focuses of habitat suitability analysis (Yi et al., 2010a,b; Parasiewicz et al., 2012).

* Corresponding author.
E-mail address: jingling@bnu.edu.cn (J. Liu).

http://dx.doi.org/10.1016/j.ecolmodel.2016.07.001
0304-3800/

Hydromorphologic units (HMUs), together with biotypes and mesohabitats are common stream habitat classification concepts at mesoscale (reach-scale) (Frissell et al., 1986; Newson and Newson, 2000; Davenport et al., 2004; Chessman et al., 2006; Pasternack et al., 2008; Ferníandez et al., 2011; Demars et al., 2012). Since in practical applications a "mesoscale" approach have been favoured since they tend to define their spatial units a priori and then to validate these units by combination of hydraulic variables. Therefore, meso-scale (reach-scale) is important in river habitat survey and modeling (Fox et al., 1998; Newson and Newson, 2000; Yi et al., 2010a,b; Gort'azar et al., 2011; Gomes and Wai, 2014; Erba et al., 2015). The concept of hydromorphologic units (HMUs) are commonly used in habitat suitability studies (Parasiewicz et al., 2014; Vezza et al., 2014a). Water depth, flow velocity and substrate grain size are usually considered to be main hydrological parameters that determine the distribution of biotypes (Yang et al., 2010; Olden et al., 2012; Gostner et al., 2013a; Schröder et al., 2013; Buendia et al., 2013; Benjankar et al., 2013).

Freshwater macroinvertebrate assemblages have provided water quality assessment programs with valuable insights for over a century (Keizer-Vlek et al., 2012; Kail et al., 2012; Kändler and Seidler, 2013; Minaya et al., 2013; Chen et al., 2014; Zhang and Liu., 2014c; Hughes et al., 2015). The biomonitoring studies primarily focused on fish communities and the water volume factors, however, nowadays more rivers are suffering from human activities, and fish species are seriously affected by fishing, water removal and reservoirs, and then benthic macroinvertebrates have become more reflective of riverine ecological conditions. Accordingly, they are considered good biological indicators of stream ecological conditions (Helson and Williams, 2013; Ligeiro et al., 2013). Therefore, indices of macroinvertebrates convert information about several attributes of mavroinvertebrate community and have been popular for assessing streams and guiding habitat restoration. Some kinds of have been developed (Pilière et al., 2014; Huang et al., 2015; Chen et al., 2014), such as the Benthic indices of Biotic Integrity (B-IBI) (Wu et al., 2012; Tan et al., 2015), Invertebrate Community Index (ICI) (Pilière et al., 2014) and MMI (Mondy et al., 2012; Mereta et al., 2013; Chen et al., 2014; Huang et al., 2015). The structure and function of macroinvertebrate assemblages are characterized by the integral indices. In addition, in studies of the benthos, greater attention should be devoted to river bottom conditions, and the correlations between main ecological factors and benthic organisms should be studied under specific river habitat conditions. Therefore, understanding the relationships of benthic macroinvertebrate communities and environment factors is important for monitoring river ecological integrity.

The primary goals of our study were (1) to classify the Hydromorphologic units (HMUs) of a stream from upper to lower reaches, (2) to build a benthic macroinvertebrate-based multi-metric index (B-MMI) in order to evaluate the ecological integrity of streams, and (3) to analyze the correlations between the main environmental factors (hydromorphological parameters and water quality elements) and B-MMI in different sites and HMU types. To build the B-MMI, data of composition, structure and function of benthic communities were evaluated. Environmental factors included hydromorphological and water quality parameters that reflect the physical habitat characteristics and the nutrient and pollution conditions of the aquatic benthos.

2. Materials and methods

2.1. Study area

River sites were selected in the Haihe River Basin, North China to represent a wide range of habitat types representative of high-quality streams from mountainous and plain reaches (Liu et al., 2014). Among the nine sub-catchments of the Haihe River Basin, the Luanhe River was semi-natural with various types of river habitats (Yang et al., 2013a,b). Therefore, we chose the Luanhe River as a typical study area to explore the relationship between hydrology and ecology in hydromorphological types (Table 1).

The Luan River has its origins near the border between Hebei Province and Inner Mongolia, and joins the Bohai Sea at Leting County after 888 km, with eight main tributaries flowing into the river. The mean annual runoff volume is 2.45 9109 m^3 of water and the size of the basin is 35,721 km^2 (Liu et al., 2009). The major types of land uses or land cover in the Luan River basin include forest, agriculture, grassland, and urban (Domagalski et al., 2007; Wu et al., 2014). The Panjiakou and Daheiting Reservoir system is the primary source of drinking water for Tianjin and Tangshan cities. River site surveys were primarily completed within one month during autumn (September-October) of 2014. The location of Luanhe River and sampling sites are shown in Fig. 1. The characteristics of the seventeen sites are shown in Table 2. Hydromorphological units (also called mesohabitats, functional habitats, or biotypes) were classified by the rules of Parasiewicz (2007) (Table 2).

2.2. Basic data collection

2.2.1. Physical and chemical samples collection

Hydromorphological parameters, such as water depth, flow velocity, substrate and water quality within mesohabitats, were surveyed in typical reaches of streams. Measurements of water depth and mean water column velocity were taken with a flowmeter in areas shallower than 1 m, and an ADCP SonTek RiverSurveyor was used in deeper areas. The size of substrates as large as sand and gravel was determined using a meter ruler, and substrates with grain sizes smaller than 2 mm were measured with a Microtrac s3500. Basic water quality parameters, such as temperature, pH, percentage of dissolved oxygen, NTU, conductivity, ORP, Chl, TDS, and Sal, were measured with a YSI6600. The other parameters were calculated based on water depth, flow velocity and substrate size, such as bottom shear stress (BSS) and Froude (Fr) and Reynolds (Re) numbers (Table 3). The Froude numbers and Reynolds have been used in other studies as descriptors in preference curves for fishes and has shown to strongly correlate with species and HMU distribution (Gostner et al., 2013b; Parasiewicz, 2007). Bottom shear stress (BSS) represents the near-bed conditions considered a key hydraulic factor for river benthos (Gostner et al., 2013b).

2.2.2. Biological samples collection

In silty reaches, benthic macroinvertebrate samples were collected with a Peterson grab (1/16 m^2 diameter). In stony reaches, benthos samples on the surface of cobbles and detritus were collected within a specific area (approximately 0.25 m^2). The samples of benthic invertebrate analysis were collected based on the procedures of EPA's RBPs (Rapid Bioassessment Protocols) (Barbour et al., 1999). More than three subsamples for each site were combined to make one composite sample for a specific site (Helson and Williams, 2013) and the average number and biomass in a unit area were calculated. The benthos samples were sieved through 0.595 mm mesh and fixed in 5% buffered formaldehyde. The invertebrate organisms were preserved in 75% alcohol after being sorted and identified to the species level. The biomass of invertebrate samples was determined by weighing the wet weights. In the laboratory, relatively large benthic organisms were directly identified with a magnifying glass and anatomical lens. Smaller benthic larvae, such as oligochaetes and insects, were identified using a microscope and were dissected when necessary for identification. Generally,