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A pilot macroinvertebrate-based multimetric index (MMI-CS) for assessing the ecological status of the Chishui River basin, China

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ABSTRACT

As the only undammed river in the Yangtze River basin and an important rare fish reserve, the Chishui River has attracted the world's attention. It was recently selected as a reference river for a pilot biomonitoring assessment within the European Union-China River Basin Management Programme. As the outcome of the project, a pilot multimetric index (MMI-CS) was developed for future assessment of the ecological status of the Chishui River basin. In this study, eight core metrics were selected and used to build the multimetric system. These metrics included the total number of taxa (TotalTax), the number of taxa of sprawlers (SprwlTax), the number of intolerant taxa (IntolTax), the Hilsenhoff biotic index (HBI), the percentage of Ephemeroptera, Trichoptera and Plecoptera (EPTPct), the number of Ephemeroptera taxa (EphemTax), the percentage of collectors (CllctPct) and the average score per taxon (ASPT). Five ecological status ratings ("Excellent", "Good", "Fair", "Poor" and "Very Poor") were established. The results of the evaluation showed that the index was reasonable and effective. The results of the assessment showed that sites with higher ecological status were distributed mainly in the upper and middle reaches of the region and that sites with lower ecological status were centrally distributed in the lower reaches. Moreover, the index should be refined and validated using additional datasets obtained in different seasons in the future for routine bioassessment within the framework of sustainable management.

1. Introduction

The Chishui River, also called the "Red River" in Chinese, is a unique, undammed natural river in southwestern China that is a major tributary of the Yangtze River. The Chishui River is not affected by dams or by the serious water pollution that commonly occurs in other rivers in China (Jiang et al., 2011). The Chishui River is famous for its developed wine industry and its high biodiversity, being located in the Rare and Unique Fish National Nature Reserve in the upper Yangtze River, a region that suffered from habitat loss due to the construction of the Three Gorges Dam (Jiang et al., 2010; Wang et al., 2007). For these reasons, the Chishui River has attracted increasing attention in China and worldwide for its ecological status. Within the European Union − China River Basin Management Programme (RBMP) project, which was conducted from 2011 to 2012, the Chishui River was selected for a pilot biomonitoring assessment with the aim of introducing the advanced experience in river management gained by the European Union (EU), establishing a sustainable management framework and enhancing integrated river basin management in the Yangtze River basin.

Macroinvertebrates are often used to assess the ecological status of streams and rivers worldwide (Vlek et al., 2004). The rationale for the all-pervading use of macroinvertebrates for this purpose is that this group of animals is rich in species with very different environmental requirements and is relatively easy to sample, and the composition of macroinvertebrate species can reflect the effects of different stressors in a given period prior to sampling. Thus, macroinvertebrate populations are good candidates for the bioassessment of river quality (Rosenberg and Resh, 1993). Under the Water Framework Directive (WFD) 2000/60/EC, macroinvertebrates are considered the most appropriate biological indicators in many EU countries (Hering et al., 2004), and the EU member states adjust water resources management countermeasures according to the results of advanced biological monitoring, which has been proven to be effective for river basin integrated management. Worldwide, many multimetric indices for biomonitoring have been developed for various types of waterbodies. The use of multimetric indices provides detection capability over a broad range of stressors and gives a more comprehensive picture of an ecosystem than can be provided by a single metric (Arndt et al., 2009; Damanik-Ambarita et al., 2016; Gabriels et al., 2010; Hong et al., 2014; Odume et al., 2012; Vlek et al., 2004). This type of methodology is recommended by the

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European Commission for assessing ecological status (Munné and Prat, 2009). Within the AQEM (Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates) and STAR (Standardization of River Classifications) projects, multimetric indices have been developed for various river types throughout Europe (Dahl and Johnson, 2004; Dedieu et al., 2016; Hering et al., 2006; OfenbÖck et al., 2004; Várbíró et al., 2011). Moreover, this methodology has been widely used in America, Africa and Asia (Aazami et al., 2015; Angradi et al., 2009; Baptista et al., 2007; Hong et al., 2014; Lakew and Moog, 2015; Touron-Poncet et al., 2014; Yung-Chul et al., 2012).

In China, macroinvertebrate-based multimetric indices were first developed for assessing the ecological status of mountain streams and rivers in East China (Wang et al., 2005; Wang and Yang, 2003). In recent years, the number of studies involving macroinvertebrate-based multimetric indices has increased steadily, and the method has been used in other regions of China, including the Qinjiang River, the Li River in Guangxi province (Cao et al., 2010; Chen et al., 2014; Lu et al., 2013), the Huntai River, the Liao River, the Naoli River, the Hailaer River in North China (Huo et al., 2013; Li et al., 2013; Qu et al., 2012; Zhang et al., 2007), the Xitiaoxi stream and small streams in Zhejiang province (Chi et al., 2012; Li et al., 2007), rivers in Shanghai city (Xiong et al., 2015), the Nanguang River in Sichuan province (Zhou et al., 2014), the Irtysh River in Xinjiang province (Wang et al., 2015), Dongting Lake (Wang et al., 2012), the Baiyangdian wetland (Xu et al., 2012), the Yangtze estuary (Zhou et al., 2009), rivers in the Lake Dianchi catchment in Yunnan province (Su et al., 2013), the Huaihe River basin (Zhang et al., 2014), the Taihu Lake basin (Cai et al., 2014; Huang et al., 2015), and rivers within the Three Gorges Reservoir catchment (Chi et al., 2016). However, most of the involved rivers have been dammed for various purposes. In recent years, China's Ministry of Water Resources has promoted river health assessment by using biomonitoring to facilitate effective water resource management in river basins. As the outcome of the RBMP project on the background of cooperation with the EU on river basin management, the aim of the present study was to develop a pilot multimetric index (MMI-CS) based on macroinvertebrates for assessing the ecological status of the Chishui River. This index may possibly be refined in the future for routine bioassessment in a sustainable management framework.

2. Material and methods

2.1. Study area

The Chishui River basin is located in the southwestern part of China. It covers a drainage area of 20,440 km^2 and originates from the northern Zhenxiong county of Yunnan province, running across Guizhou and Sichuan provinces and finally joining the Yangtze River in Hejiang county. Its main tributaries include the Weixin River, the Gulin River, the Yanjin River, the Baisha River, the Tongzi River, and the Xishui River (Cai et al., 2015; Zou et al., 2010). The mainstream, with a total length of 436.5 km, is divided into upper, middle and lower reaches; these extend from the headwaters to Maotai town, from Maotai town to Chishui city, and from Chishui city to Hejiang county, respectively. The annual temperature in the river basin, which has a subtropical monsoon climate, ranges from −5 to 39 °C. The annual rainfall in the plateau of the upper reach and in the hill area of the middle-lower reaches is 900–1000 mm and 1000–1500 mm, respectively (Jiang et al., 2010). Sixty percent of the annual rainfall occurs between June and September. The water level in the river fluctuates significantly between the drought and flood seasons due to discharge, mainly from rainfall. The soil in the river basin consists primarily of laterite, and extensive erosion into the river usually occurs in the summer due to flooding. The upper and middle reaches of the river basin lie in the transitional area between Yungui Altiplano and the Sichuan basin and contain typical karst landforms. The altitude of small tributaries with steep slopes in the upper reaches is often more than 1000 m. The altitude of the middle reaches features a softer slope, and some terraces located on both sides of the river range from 500 m to 1000 m. At the lower reaches, the width of the river may extend to 200 m (Jiang et al., 2010; Jiang et al., 2011; Wang et al., 2007).

Essentially no industrial wastewater is discharged to the upper reaches of the Chishui River basin; here, the pollution sources are mainly domestic sewage, rural pesticides and fertilizers. In this section, the water quality is good (Class I–II of surface water according to the national standard GB3838-2002) due to the good self-purification capacity. Several large wineries, coal mining enterprises and towns are distributed along the middle reaches, resulting in the discharge of tons of untreated wastewater directly into the river. Moreover, untreated wastewater and garbage from passing ships, as well as pesticides and fertilizers from farmland, are directly discharged into the river. The water quality in this section sometimes reaches Class II of surface water due to the large discharge and strong self-purification ability of this region. The water in the downstream region is perennially affected by industrial wastewater, urban wastewater, sewage and garbage from passing ships, and farmland pesticides and fertilizers, leading to considerable amounts of serious pollution and bad water quality. The water quality has only once reached Class IV (Guang, 2009). Among the tributaries, the Weixin River is also seriously polluted by wastewater from towns along the river, and the Yanjin River suffers from heavy organic pollution due to wastewater discharge from numerous small wine workshops (Wang, 2016).

2.2. Sampling sites and data collection

In this study, according to the theory of functional process zones (FPZs) (Thorp et al., 2006), the distribution of macroinvertebrates is assumed to be significantly influenced by river morphology and natural conditions. Therefore, the sampling sites used in this study were chosen to meet the following principles: a) the sampling should cover the river basin; b) the sampling should consider different landforms and natural conditions; and c) the sampling should consider the influence of various land uses. After analyzing the river morphology and the natural conditions, including the elevation, meander degree, slope, width of valley, precipitation, etc., with the aid of a geographic information system (GIS), the FPZs in the river basin were defined (Thorp et al., 2006), and the sampling sites in different FPZs were chosen. Two surveys were conducted during 2010–2011. A pilot trial sampling was conducted in November 2010 to test the implementation feasibility of the sampling plan. A formal sampling was conducted in April 2011. In the trial sampling period, 10 sampling sites were visited, of which 4 were in the mainstream and 6 were in the tributaries. In the formal sampling period, 72 sampling sites were established, of which 27 were in the mainstream and the remaining 45 were in the tributaries. The 10 sampling sites visited during the trial sampling period were revisited during the formal sampling period; these sites included CS01, CS09 CS21, CS16, YJ02, XS01, XS07, XS09, BS02 and GL01. The sampling sites included up-, middle- and downstream locations and covered the main tributaries. Detailed information on the sampling sites is provided in Fig. 1 and Appendix A.

The sampling time was limited to winter and spring (dry season) because the water level of the Chishui River during this period was low, facilitating the sampling of biological samples, whereas in the wet season, the water level was high in most river reaches, resulting in great difficulty in collecting macroinvertebrate samples from such a large river. Biological (macroinvertebrate) and environmental (physical-chemical and hydromorphological) data were collected at each sampling site. The width of the river was measured using a laser rangefinder, and the flow velocity was measured using the float method over a 5-m distance using a laser rangefinder. Temperature, conductivity, pH and turbidity were measured *in situ* using multi-parameter water quality analyzers (YSI 6600). Total nitrogen, total phosphorus, ammonium