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Longitudinal and seasonal patterns of macroinvertebrate communities in a large undammed river system in Southwest China

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ABSTRACT

Identifying naturally-regulated spatial and temporal variations of benthic macroinvertebrates is critical to effective assessment and conservation of aquatic ecosystems, but little is known about these variations in large rivers in East Asian monsoon region. Here, we address this issue by measuring within-one-year longitudinal and seasonal variability in macroinvertebrate assemblages in such a broadly natural river across its whole watershed. Along longitudinal gradients, taxon richness, Shannon–Wiener diversity and mayflies and caddisflies significantly decreased downstream but chironomids and oligochaeta increased. Taxon richness, diversity indices, and abundance of most taxa all had lowest value in summer. Assemblage structure showed both significant but larger longitudinal than seasonal variations, with a clear separation of upstream and most midstream sites from downstream ones in ordination plot. Different environmental and spatial variables were significant for distinguishing macroinvertebrate assemblages among four seasons, although substrate and PCNM1 emerged as important in all seasons. Variance partitioning analyses indicated stronger environmental control than spatial structuring of community composition in all seasons, with pure environmental factors explaining most community variation. These observed patterns contribute to understanding of sources of uncertainty in bioassessment and thus have implications for ecological monitoring and assessment using macroinvertebrates in rivers in monsoon regions.

1. Introduction

The spatial and temporal variations influence the manifestation of patterns and processes in nature (Levin, 1992), particularly in hierarchically structured systems such as river networks (Parsons et al., 2003; Leung and Dudgeon, 2011). Globally speaking, streams and rivers are extremely heterogeneous ecosystems with high spatio-temporal variability (Townsend, 1989; Ward et al., 2002; Beche et al., 2006). Benthic macroinvertebrates are promoted as excellent indicators of lotic environment monitoring and impact assessment. However, the significantly spatial (within stream, among streams within regions and among regions or ecoregions) (e.g. Heino et al., 2002; Heino et al., 2004; Stendera and Johnson, 2005; Leung and Dudgeon, 2011; Pan et al., 2015a) and temporal (diel, seasons and years) (e.g. Furse et al., 1984; Mykrä et al., 2008; Leung and Dudgeon, 2011; Li et al., 2015) variability of macroinvertebrate communities hindering comparability has drawn their main criticism (Rosenberg and Resh, 1993).

A clear identifying of spatial and temporal trends of these communities could enhance our understanding of the ecology of macroinvertebrates, definition of impacts of anthropogenic or natural disturbances on lotic communities, and assessment and conservation of lotic biodiversity. Although numerous studies have examined the spatio-temporal patterns of stream macroinvertebrates worldwide (e.g. Furse et al., 1984; Li et al., 2001; Mykrä et al., 2008; Vidal et al., 2014), few such studies have been carried out in large rivers (Zilli and Marchese, 2011; McCord and Kuhl, 2012; Vaughan and Ormerod, 2012; Floury et al., 2013), especially in rivers of East Asian monsoon region (Jiang et al., 2010, 2013; Pan et al., 2015b). The difficulty in collecting samples from large rivers, due to their greater width and depth, and their complex habitats and hydrology have led to lack of effective studies in these systems (Junk et al., 1989; Battle et al., 2007). Moreover, the current benthic studies in large rivers mostly focused on river sections, rather than across the whole watershed (Battle et al., 2007; Jiang et al., 2010). Compared to wadeable

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streams, however, the physical characteristics of large river systems varied more dramatically along longitudinal gradient (from small streams to deep mouth) (Vannote et al., 1980), and their habitat heterogeneity is generated and sustained by variable levels of human impacts (usually increase downstream) and more complex hydrological regime (e.g. seasonal flood pulses, hydrological connectivity) (Ward and Stanford, 1995; Allan and Benke, 2005). These all result in spatial and temporal mosaic of physical and chemical variables that drive the spatio-temporal variability of macroinvertebrate communities (Zilli and Marchese, 2011).

The East Asian monsoon region supports long history and environment features that contribute to a rich biodiversity, and is experiencing the impacts of rapid human development. However, the ecology of benthic macroinvertebrates in this region has yet not been well studied (Li et al., 2012). Recent studies have highlighted the limited considerations given to the spatial and seasonal patterns of macroinvertebrate assemblages in East Asian rivers (Chao et al., 2012; Zhang et al., 2012). Summer monsoons usually cause seasonal floods in these rivers (Sun et al., 2010; Wei et al., 2014), which virtually have a pervasive influence on all aspects of river ecology (Flecker and Feifarek, 1994; Naiman and Bilby, 2001). Some recent studies reported that taxa richness and abundance of macroinvertebrate declined in wet seasons in Chinese monsoonal streams (Leung and Dudgeon, 2011; Chen et al., 2014). Although such monsoonal effects are assumed to occur widely in lotic systems, a scarcity of researches of spatial and temporal patterns in large rivers limits our ability to generalize about their implications in these ecosystems.

In this study, we selected the Chishui River, a large subtropical monsoonal river in southwestern China, to examine the longitudinal and seasonal patterns of macroinvertebrate communities from headwater to mouth across four seasons. Being the last undammed primary tributary of the upper Yangtze River, this river basin supports numerous rare and endemic fish species and is considered as a hotspot and refuge for lotic biodiversity conversation (He et al., 2011). Nevertheless, knowledge of benthic communities in this region is still very scare and inadequate (Jiang et al., 2010, 2011). In this study, our main objectives were: 1) to determine how biodiversity and community characteristics varied among 3 regions (upstream, midstream and downstream) and 4 seasons (spring, summer, autumn and winter); 2) to examine how environmental and spatial filters drive assemblage composition among different seasons.

2. Materials and methods

2.1. Study area and sites selection

The study area has been described previously (Jiang et al., 2010, 2011), thus we restate the details briefly here. The Chishui River (27°20′ − 28°50′ N, 104°45′ − 106°51′ E), the last undammed primary tributary of the upper Yangtze River, covers a basin area of 20 440 km^2. The main river flows about 440 km from its headwater in Yunnan Province to its mouth in Sichuan Province. As the core zone of the National Nature Reserve for rare and endemic fishes of the upper Yangtze River (NNRYR) constructed in 2005, the Chishui River provides vital habitats and refuges for endemic aquatic organisms of upper Yangtze River (Wu et al., 2010) and is thus of importance in biodiversity assessment and conservation. The river basin experiences a subtropical monsoon climate with concentrated rainfall in summer, which causes flood and wash red soil in to the river (actually “Chishui” means red river in Chinese).

We randomly selected 16 representative sites (upstream, 6; midstream, 5; and downstream, 5) (Fig. 1) based on a previously investigation including 43 sites across the basin (Jiang et al., 2010). The 16 sites were selected based on two major criteria: first, they should represent different habitats including high plain and low elevation areas, lentic and lotic habitats, small streams and large rivers, shallow and deep channels along the longitudinal gradient; second, they should evenly distribute in upstream, midstream and downstream of the studied river system.

2.2. Data collection

Benthic macroinvertebrates were seasonally collected at 16 sites (Fig. 1) in April, July, October 2007 and January 2008, respectively. At each sample occasion, three quantitative samples were taken in principal habitats with a Surber sampler (30 × 30 cm in area, with 500 μm in mesh size) or a modified Petersen grab (0.0625 m^2 in area) (in downstream and some midstream occasions where water depth was too great for Surber sampling), sieved with a 500 μm sieve in the field. Specimens were manually sorted out from sediment on a white porcelain plate in the field laboratory and preserved in 10% formalin. Animals were mainly identified to species or genus in the laboratory, according to the relevant references (Brinkhurst, 1986; Morse et al., 1994; Wiggins, 1996; Dudgeon, 1999; Epler, 2001; Zhou et al., 2003), and counted. Wet weight of each taxon was obtained with an electronic balance after being blotted, and then dry weight (mollusks without shells) was calculated according to the ratios of dry/wet weight and tissue shell weight reported by Yan and Liang (1999).

On each sample occasion, environmental variables were measured prior to macroinvertebrate sampling. Altitude, latitude and longitude were registered using a Garmin GPS-76 system. Channel width (using a Ranger Laser Finder instrument) and water depth were averaged from several equal transects (usually 10, at least 7). Current velocity was determined in the middle of the sampling location with a LJD-10 flow-meter. Water temperature, dissolved oxygen (DO), conductivity, and pH were measured in the field with a WTW Multi 340i probe. Substratum was assigned into one of the five types: (i) silt plus clay (<0.06 mm), (ii) sand (0.06−2 mm), (iii) pebbles plus gravel (2−64 mm), (iv) cobble (64−256 mm), and (v) boulder bedrock (>256 mm), and their percentages were estimated at each site using a 1 m^2 grid. Water was collected to quantify alkalinity, hardness, calcium (Ca^{2+}), chemical oxygen demand (COD_{Mn}), ammonium nitrogen (NH_4-N), whole phosphorus (TP), and phosphate phosphorus (PO_4-P). All of the above physicochemical parameters were measured in the field laboratory according to the environmental quality standards for surface water of China (Wei et al., 1989) and the standard methods for observation and analysis in China (Huang et al., 1999).

2.3. Data analysis

One-way, repeated-measures analysis of variance (ANOVA) was carried out on the environmental and macroinvertebrate data (total density, biomass, richness, Shannon−Wiener diversity, and abundance of dominant groups) to detect their difference among 3 regions (upstream, midstream and downstream) and 4 seasons. The repeated-measures analysis was chosen because the same sites were sampled on four subsequent occasions, resulting in temporally non-independent data. In cases when the assumption of data sphericity was violated, the results of the within-subjects analyses were corrected with the Greenhouse-Geisser method (Quinn and Keough, 2002). When the between-subject effects of the ANOVAs were significant, we conducted pairwise comparisons between regions. These comparisons were carried out with Tukey's honestly significant difference (HSD) multiple comparison technique. In cases of persistent heteroscedasticity (results of