Ecological Indicators 60 (2016) 265–274

Contents lists available at ScienceDirect

Ecological Indicators

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

Diatoms are better indicators of urban stream conditions: A case study in Beijing, China

Xiang Chen[a,b], Weiqi Zhou[a,b,*], Steward T.A. Pickett[c], Weifeng Li[a,b], Lijian Han[a,b], Yufen Ren[a,b]

[a] State Key Laboratory for Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, No. 18 Shuangqing Road, Haidian District, Beijing 100085, PR China
[b] University of Chinese Academy of Sciences, No. 19A Yuquan Road, Beijing 100049, PR China
[c] Cary Institute of Ecosystem Studies, Box AB, 2801 Sharon Turnpike, Millbrook, NY 12545, USA

ARTICLE INFO

Article history:
Received 8 November 2014
Received in revised form 23 June 2015
Accepted 24 June 2015
Available online 24 July 2015

Keywords:
Benthic diatoms
Urban stream
Urban–rural gradient
Nutrients
Indicator species
Beijing

ABSTRACT

Urbanization dramatically affects hydrology, water quality and aquatic ecosystem composition. Here we characterized changes in diatom assemblages along an urban-to-rural gradient to assess impacts of urbanization on stream conditions in Beijing, China. Diatoms, water chemistry, and physical variables were measured at 22 urban (6 in upstream and 16 in downstream) and 7 rural reference stream sites during July and August of 2013. One-way ANOVA showed that water physical and chemical variables were significantly different ($p < 0.05$) between urban downstream and both reference and urban upstream sites, but not between reference and urban upstream sites ($p > 0.05$). Similarly, structural metrics, including species richness (S), Shannon diversity (H′), species evenness (J′) and Simpson diversity (D′), were significantly different ($p < 0.05$) between urban downstream and both reference and urban upstream sites, but not ($p > 0.05$) between reference and urban upstream sites. However, diatom assemblages were very different among all sites. *Achnanthidium minutissima* was a consistent dominant species in reference sites; *Staurosira construens* var. *venter* and *Pseudostaurosira brevistriata* were the dominant species in urban upstream sites; and *Nitzschia palea* was the dominant species in urban downstream sites. Clustering analyses based on the relative abundance of diatom species, showed all the samples fit into three groups: reference sites, urban upstream sites, and urban downstream sites. Canonical correspondence analysis (CCA) and Monte Carlo permutation tests showed that concentration of K^+, EC, TN, Cl^- and pH were positively correlated with relative abundance of dominant diatom species in urban downstream samples; WT and F^- were correlated with reference and urban stream diatom composition. Our results demonstrate that the composition of diatom species was more sensitive to urbanization than the water physical and chemical parameters, and that diatom assemblage structure metrics more accurately assessed water quality. Some species, such as *Amphora pediculus* and *Cocconeis placentula* were among the dominant species in low nutrients stream sites; however, they were considered to be high nutrient indicators in some streams in USA. We suggest using caution in applying indicator indices based on species composition from other regions. It is necessary to build a complete set of diatom species data and their co-ordinate environment data for specific regions.

1. Introduction

China began a period of rapid urbanization with the reform and opening in the 1980s. The proportion of urban population increased from 17.9% of the population in 1978 to 52.6% in 2012 while the urban built-up area grew by 78.5% (Bai et al., 2014). The rapid urbanization has caused a series of complex environmental problems, for example, the alteration of hydrosystems (Walsh et al., 2005; Hopkins et al., 2015), loosening of biogeochemical cycles (Pickett et al., 2011), warming of urban meso-climate (Zhou et al., 2004; Li et al., 2012a,b; Zhou et al., 2014), and impairment of biodiversity (Angold et al., 2006; Grimm et al., 2008).

Urbanization affects hydrosystems dramatically by altering hydrology, channel morphology, water quality and aquatic biota (Dunne and Leopold, 1978; Newall and Walsh, 2005). In urban areas, water quality degradation may be associated with the

* Corresponding author. Tel.: +86 10 62849268; fax: +86 10 62915732.
E-mail addresses: xiang8234@126.com (X. Chen), wzhou@rcees.ac.cn (W. Zhou).

http://dx.doi.org/10.1016/j.ecolind.2015.06.039
1470-160X/

increased areas of impervious surfaces (Ren et al., 2003), with piped stormwater drainage systems (Dunne and Leopold, 1978), and with effluent from wastewater systems (Gray and Becker, 2002). The increase of impervious surface cover in catchments results in the increase of surface runoff (Arnold and Gibbons, 1996; Zampella et al., 2007). Consequently, the surface pollutants enter directly into urban streams reducing water quality, through increases in such factors as in Chemical Oxygen Demand (COD) and ammonium-nitrogen (NH_3-N) (Kuang, 2012).

Changes in stream hydrology, morphology, and water quality caused by urbanization have great impacts on aquatic organisms, and the cumulative changes of urbanization impacts on streams can be best reflected by resident biota (Walker and Pan, 2006). Studies of urbanization impacts on aquatic biota have typically used the microbial, macroinvertebrate, and fish assemblages (Paul and Meyer, 2001). However, there are fewer studies of the response of algae to urbanization (Paul and Meyer, 2001; Wenger et al., 2009).

Diatoms, a species-rich benthic algal assemblage readily affected by habit physical, chemical and biological disturbances and stresses, have become useful ecological indicators of stream ecosystem health because of their rapid rate of reproduction and their basal role in the food web (Stevenson and Bahls, 1999; O'Driscoll et al., 2012; Gray and Vis, 2013). Diatoms are considered as an ideal group to response of aquatic environments (Adams et al., 2013) and they have long been used to indicate water quality in rivers and streams in the United States and European countries (Stevenson et al., 2010). Most studies of urbanization impact on diatom assemblages have been attributed the effects to sanitary sewage and stormwater runoff compared to reference areas (Sonneman et al., 2001; Newall and Walsh, 2005; Walker and Pan, 2006). Diatoms have been increasingly used for assessment of urban streams in recent years (Potapova et al., 2005; Bere et al., 2014). However, there are a few studies of the distribution and changes of the diatom assemblages in cities.

Many diatom taxa are considered to be cosmopolitan, and the diatom indices based on species composition have been applied straightforwardly in different countries. However, evidence suggests that the diatom indices developed in one area are less successful in other areas because the climate, geology, local environment conditions and habitat, which are considered to be the main factors determining composition of the algal assemblages in streams, would be enormously different between regions or continents (Stevenson, 1997; Potapova et al., 2005; Kelly et al., 2008). To understand why the indices may not translate across regions, Besse-Lototskaya et al. (2011) evaluated seven trophic indicator indices by comparing trophic scores of diatom species in Europe. They found that the trophic indicator indices were a good water quality assessment tool, but the indices should be used carefully in other areas. Potapova and Charles (2007) developed diatom metrics to assess river eutrophication in the United States, they noticed the metrics were used better for monitoring the U.S. rivers than some similar metrics were created for Europe waters.

Diatom assemblages are widely used as indicators of water quality and stream ecological health in many countries and regions, but the physical and chemical parameters are the common means of monitoring water quality in China. Therefore, there are as yet very few studies of diatom assemblages in Chinese rivers (but see Tang et al., 2006 and Wu et al., 2012) that would allow their suitability as indicators to be assessed. The objectives of this research were: (1) to quantify the variations in water quality and benthic diatom assemblage structure along an urban-to-rural gradient in Beijing, China; (2) to examine whether the diatom assemblages can accurately reflect the variation in urban water quality; and (3) to construct datasets of diatom species responses to Beijing water quality. It is hoped that our results can promote the diversification of water quality monitoring in China.

2. Materials and methods

2.1. Study area

Situated in northeast China, Beijing adjoins the Inner Mongolian highland to the northwest and the great northern plain to the south, and covers a total area of 6410.54 km^2. Beijing city is located in the north temperate zone and has a moderate continental climate. The annual average temperature is 12 °C, with a mean monthly maximum of 31 °C recorded in July and a mean monthly minimum of −8 °C recorded in January. Annual mean precipitation is 588.1 mm, with most of the precipitation (about 72%) occurring in July and August with <2% occurring during the winter (Zhu et al., 2012).

In 2013, the population of Beijing was estimated at 21.14 million inhabitants (Beijing Municipal Bureau of Statistics (BMBS), 2014). The huge and rapid increase of population created tremendous pressure on the municipal services, such as garbage collection and treatment, sewage treatment, and urban storm drainage. The drainage channels of Beijing therefore receive untreated or semi-treated wastewater from many different domestic and industrial sources, as well as pollution from surface runoff. This may reduce the richness of algal, invertebrate, and fish communities and result in eutrophication (Paul and Meyer, 2001).

Our sampling sites were located within the city boundary, mainly along the Jingmi Channel and drainage channels in the fifth ring of Beijing (Fig. 1). The headwater of the Jingmi channel is the Miyun reservoir. Located in the Yanshan Mountains, it is the main source of drinking and domestic water in Beijing. Jingmi channel is 112.7 km long and acts as the main water supply conduit for the entire city area. Consequently it is well protected along the way to the storage pool, Tuancheng Lake. We compared water quality and diatom samples from (1) the Jingmi channel between Tuancheng Lake and the city center, labeled the urban upstream sites, (2) the channels draining the core city, labeled the urban downstream sites, and (3) a reference stream on Yan Mountain. Duijiuyu, the reference stream runs 14.4 km from Mayi Mountain to Mayufang reservoir, and is similar to the headwater stream of Miyun reservoir. The main land use along the reference stream is forest associated with agriculture and farmers' residences.

2.2. Diatom sampling and identification

Twenty-nine sites were sampled for diatom assemblages during late July and August of 2013. Of the 29 sites, 7 sites were in the reference stream, 22 sites were in city streams, with 6 sites upstream of the urban core, and 16 sites downstream of urban core. In order to avoid different types of substrata influence benthic diatom assemblage composition, we collected the epilithon diatoms on hard substrates (Eloranta and Andersson, 1998). The benthic diatoms were collected from the lotic parts of the sampling sites by scraping about five stones in natural streams or five areas on the cement surfaces in artificial streams, using a hard toothbrush to collect the biofilms. Samples were preserved in 100 ml plastic bottles and fixed in 4% formaldehyde. In the laboratory, about 5–10 ml samples of the diatom suspensions were cleaned of organic materials with concentrated nitric acid, and the treated samples were washed until they reached a circumneutral pH (Stoermer et al., 1995; Gray and Vis, 2013). The permanent diatom slides were mounted in Naphrax (Brunel Microscopes Ltd., Hazelbrook, Wiltshire, UK, RI = 1.73). Slides were scanned with a light microscope (Olympus BX51, Olympus, Tokyo, Japan) at 1000× magnification. A minimum of 500 diatom valves was counted on each slide; fewer valves were counted on some slides when diatoms were scarce. Valves were identified to the species or sub-species level. References for diatom taxonomy were Krammer and Lange-Bertalot (1986, 1988, 1991a,b), the database of the Patrick Center of The