ARTICLE IN PRESS

Ecological Indicators xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Influences of hydrodynamic conditions on the biomass of benthic diatoms in a natural stream

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ARTICLE INFO

Keywords:
Benthic diatom
Biomass
Hydrodynamic characteristics
Flow velocity
Water depth
Shear stress

ABSTRACT

Studies on benthic algae and hydrodynamic characteristics are rarely conducted in natural streams. In this study, a natural stream was selected as a test field. First, we sampled the benthic diatoms on site. Then, we measured stream physicochemical characteristics in the laboratory. Finally, we estimated hydrodynamic characteristics using a numerical simulation. On these bases, the corresponding relations between benthic diatom biomass and stream velocity and shear stress at different sections were studied in the 1D case, and the corresponding relations between benthic diatom biomass and stream velocity and depth were studied in the 2D case. The results show that the suitable flow range for benthic diatoms is approximately 0.85–1 m/s and the suitable shear stress is approximately 24–28 N/m^2 in the 1D case. In the 2D case, the suitable velocity and stream depth are 0.9–1.1 m/s and 0.40–0.48 m, respectively. Therefore, both along the stream and in cross-section, there is always a range with suitable hydrodynamic characteristics to support a relatively high biomass of benthic diatoms. Outside of this range, however, the biomass decreases regardless of whether the values of the hydrodynamic characteristics are higher or lower. The study conclusion may provide a reference for stream ecological assessment and restoration.

1. Introduction

Algae are a highly diverse group of organisms that have important functions in aquatic habitats. According to their required living conditions and ecological growth area, algae can be divided into types or groups, such as *Plankton, Benthos, Algen fliessender Gewasser, Aerophytische Algen, Epibionten*, and others (Fott, 1959). The community of microscopic algae that grow attached to a variety of submerged substrata is an essential component of lotic ecosystems. This community, called benthic algae, performs a range of ecosystem functions, including primary production (Poulíčková et al., 2008), and constitutes the food source for several invertebrates and fishes (Turner and Edwards, 2012).

Benthic algae, including diatoms, Chlorophyta and Cyanophyta, have important functions in riverine ecological systems; as the bottom of the nutrition chain, they are a vital link in the nutrient circulation and energy flow of riverine ecological systems. Benthic algae are also important chemical regulators and absorb chemical elements such as heavy metals. In addition, benthic algae can stabilize such substances in lotic systems. Moreover, these organisms provide a rich living environment and important habitat for other aquatic species (Biggs and Kilroy, 2000; Hill et al., 2003; Hauer and Lamberti, 2011). In addition, they can be used as bioindicators of aquatic ecosystems due to their ability to reveal the effects of pollutants and abiotic factors (Montuelle et al., 2010; Lambert et al., 2015). In this paper, we chose the most widely distributed benthic diatom as the research object.

Based on observations in natural streams (Uehlinger et al., 2003; Boulêtreau et al., 2006, 2008, 2010; Choudhury et al., 2015) and in flumes (Ghosh and Gaur, 1998; Hondzo and Wang, 2002; Cardinale, 2011), a number of studies have investigated the factors influencing the accrual of benthic algae. Factors influencing the accrual and loss of algae biomass can be categorized as resources, disturbance, grazing, and other factors (Fig. 1) (Stevenson et al., 1996). Experimental studies have shown that light, nutrients (nitrogen and phosphorus), and temperature are the main variables controlling productivity and biomass gain (Cibic et al., 2012; Zhang et al., 2016). Westlake (1981) reported that the system will not be nutrient limited when $P > 30\ \mu g/L$ and $N > 1\ mg/L$ in streams. Therefore, Hilton et al. (2006) considered nutrients to be the driving force for algae accrual; however, nutrients will not be a limiting factor in eutrophic streams. In streams, diatom biomass reaches peak abundance at a certain level with suitable bed light levels (Sellers and Bukaveckas, 2003; Yang and Flower, 2012). Temperature primarily affects algal photosynthetic metabolism through its control of enzyme reaction rates (Stevenson et al., 1996). Natural or

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http://dx.doi.org/10.1016/j.ecolind.2017.05.061
Received 12 December 2016; Received in revised form 12 April 2017; Accepted 23 May 2017
1470-160X/

Please cite this article as: Wang, H., Ecological Indicators (2017), http://dx.doi.org/10.1016/j.ecolind.2017.05.061

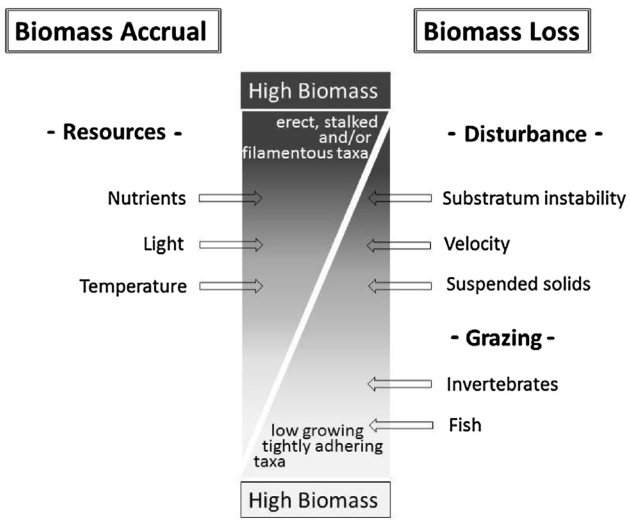

Fig. 1. Summary of the disturbance-resource supply-grazer concept for the control of benthic algal development in streams.

artificial substrates will affect colonization patterns or population size (Danilov and Ekelund, 2001; Liboriussen and Jeppesen, 2006).

Flow plays a defining role in the physical structure, distribution and abundance of biota and ecosystem processes in rivers (Dewson et al., 2007). Whether the impact of hydrodynamic conditions on benthic algae is direct or indirect is controversial. Direct effects are such physical effects as shear stress, which will promote or restrict algae growth. Indirect effects change the distribution of resources such as nutrients and illumination. Moderate increases in current have been shown to increase primary production (Labiod et al., 2007; Davie and Mitrovic, 2014), respiration, and mineral uptake (Larned et al., 2004). A higher current velocity could also stimulate physiological processes such as nutrient uptake and photosynthesis (Besemer et al., 2007).

Studies examining epilithic algae–flow relationships in streams are potentially useful because they involve natural conditions that are difficult to replicate in a laboratory setting (e.g., water quality, light, grazing invertebrates and fish), while reducing the expense and logistical challenges associated with whole-stream manipulations (Hart et al., 2013). Therefore, one reach of approximately 1 km was chosen as a natural testing field in this study. The influences of hydraulic conditions on benthic diatoms were researched in a field investigation. All the hydrodynamic characteristics were obtained on the basis of numerical simulation.

2. Materials and methods

2.1. Study site

This research was conducted in the Baitiao River (Chengdu, Sichuan), which is one of six rivers below the Dujiangyan irrigation project and Zipingpu hydropower station and is a water source for Chengdu downstream (Fig. 2). The stream bed substrate was composed of pebbles from a few centimeters to tens of centimeters along with coarse to fine sand. The stream was at its base flow, and no flooding

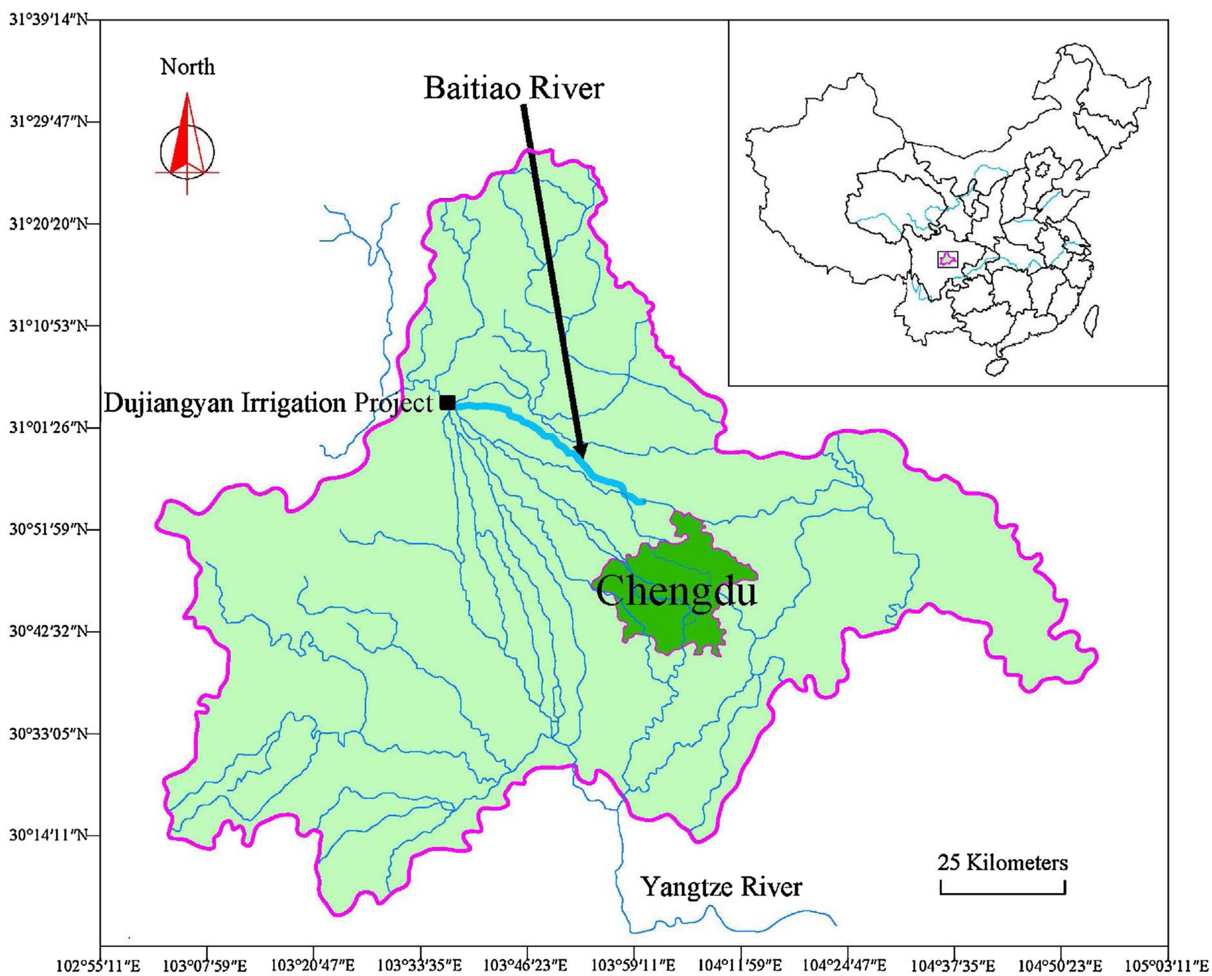

Fig. 2. Location of the Baitiao River and the studied reach.